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All communications relating to this Journal should be addressed to the Dean of the Faculty of Science, University of Tokyo.

NOTES ON TWO DEVONIAN TRILOBITES FROM THE KITAKAMI MOUNTAINS IN JAPAN

By

Teiichi KOBAYASHI

With Plate I.

Devonian is the least known system in Japan. Fossils of the period are reported from only four places (KOBAYASHI and IGO, 1956). At these localities trolbites are exceedingly rare. One of them is *Cheirurus* (*Crotalocephalus*) *japonicus* KOBAYASHI and IGO, 1956, from the Kimmamichi formation in the Hida plateau which used to be considered Gotlandian, but was proven to be early Middle or late Lower Devonian. At the same time it reveals the affinity of the Kimmamichi fauna with Australia on one side and with Europe through Central Asia and Asia Minor on the other.

Because trilobites are keen indices to the geological age as well as the life province, it is the aim of this study to see how far one can learn out of *Dechenella minima* OKUBO, 1951, and *Bronteus* (*Thysanopeltis*) *paucispinosa* OKUBO, 1951, from the Nakazato series of the Kitakami mountains. The former is represented by a cranidium and the latter by a pygidium. They are, though imperfect, enough to judge OKUBO's identification. He noted that most species of *Dechenella* are reported from Middle Devonian and *Thysanopeltis* is a subgenus of *Bronteus* which occurs in Europe mostly in Lower and Middle Devonian.

As discussed below, the reference of the former to *Dechenella* of *Dechenella* is quite warranted. Through the monographic works (1921, 1950), R. and E. RICHTER have shown that the subgenus is restricted in Europe and Morocco to the Givetian stage and the species in Yunnan and North America are most probably coeval with the European ones. Therefore *D.* (*D.*) *minima* may not be a non-Givetian exception.

As pointed out by REED (1925), PRANTL and PŘIBYL (1946) and others, two morphic groups can be distinguished in *Scutellum* (*Thysanopeltis*). The *speciosus* group or *Thysanopeltis*, s. str. is so far known only from Europe, while the *acanthopeltis-clementinum* group or *Thysanopeltella*, nov. to which *paucispinosa* belongs occurs in Europe in the Eifel stage and is distributed from the Urals to Eastern Asia through Turkestan. Such a wide distribution of this group is in support of RICHTER's view (1914) on the pelagic habit of *Thysanopeltis* (*s. l.*). *Scutellum* (*Thysanopeltella*) *paucispinosa* (OKUBO) can briefly be said *Scutellum* (*Scutellum*) *furciferum* (BARRANDE) with a spine issuing from each pleura on the pygidium. Therefore PRANTL and PŘIBYL's opinion (1946) on the derivation of *Thysanopeltella* from the *furciferum* group of *Scutellum* suites for the origin of *paucispinosa*, although the remote distance can hardly be overlooked.

It is certainly a remarkable fact that *Thysanopeltella* and *Crotalocephalus* are

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unknown from North America and *Dechenella* s. str. is, though occurs in North America, not so well developed as in Europe. Therefore *these trilobites on the whole indicate the faunal connection between Japan and Europe.* In discussing the early Ordovician palaeogeography (1955) I have shown that the faunal connection was maintained through geosynclines for a long distance. From this viewpoint the transcontinental distribution of these trilobites is of special interest.

Assuming that the homotaxial deviation is negligible for these trilobites, their ages suggested by the geological ranges or the acmic prominence of these subgenera are as follows:

1. *Dechenella (Dechenella) minima* OKUBO from Hikoroichizawa; Givetian.
2. *Scutellum (Thysanopeltella) paucispinosa* (OKUBO) from Omorizawa; Couvinian or thereabout.
3. *Cheirurus (Crotalocephalus) japonicus* KOBAYASHI and IGO from Kimmamichi; Emsian, if not Couvinian.

Here I record my sincere gratitude to the late Prof. R. RICHTER of the Senckenbergiana, Frankfurt am Maine, Prof. Victor VAN STRAEHLEN of the Musée Royal d'Histoire Naturelles de Belgique, Bruxelles, Prof. I. A. BROWNE of the University of Sydney and Dr. K. DOI of the Mineralogical Institute of our university for securing some copies of references.

Family Scutelluidae R. and E. RICHTER, 1925.

RICHTERS' classification (1956) is the latest in which the family divided into 3 genera (*Eobronteus*, *Scutellum* and *Stoermeraspis*) and 6 subgenera of *Scutellum* (*Kolichapeltis*, *Paralejurus*, *Planiscutellum*, *Scabriscutellum*, *Scutellum* and *Thysanopeltis*). Here *Thysanopeltella* is segregated from *Thysanopeltis* as a new subgenus of *Scutellum*.

It is noted further that *Bronteus longispinifer* MITCHELL, 1887, from New South Wales has a very small, but relatively broad, well rounded pygidium with entire margins. The conical axial lobe of the thorax, abruptly tapering backwards, is very unusual; its pleurae are protruded into long spines. These aspects are so aberrant that I think that the species indicates an unnamed genus by itself. The associated cranidium, though its Scutelluidae-nature is represented, is unfortunately very imperfect.

Genus *Scutellum* PUSCH, 1833

Subgenus *Thysanopeltella* KOBAYASHI, new subgenus

Diagnosis:—*Scutellum* with spines of definite number on pygidium issuing regularly in accordance with pleural segmentation; axial lobe trilobed; post-axial median rib simple or bifurcate; each spine projected from a branch of the rib or the median groove in bifurcate forms; 7 additional spines on each side.

Type:—*Bronteus acanthopeltis* BARRANDE, 1852.

Remarks:—It has been a moot question whether the marginal spines on the pygidium can be evaluated as generic or subgeneric distinction in the Scutelluidae. While *Thysanopeltis* which is characterized by them was ignored by BARRANDE (1852), REED (1925), WEBER (1932) and others, it was accepted as a valid genus or subgenus by GÜRICH (1909), RAYMOND (1913), RICHTER (1914, 56), MAILLIEUX (1938), PRANTL and PŘIBYL (1946), PRANTL (1949), OKUBO (1951) and HUPÉ (1953, 55).

Thysanopeltis was erected by HAWLE and CORDA (1947) on *Thysanopeltis speciosus* HAWLE and CORDA, but BARRANDE (1852), denying its validity, redefined the species and proposed *B. thysanopeltis* for it. REED distinguished two subgroups in the *Thysanopeltis* group as follows:

1. *Acanthopeltis* subgroup having marginal spines corresponding with ribs in number and position.
2. *Speciosus* group having more numerous spines unrelated to the ribs.

Likewise PRANTL and PŘIBYL recognized two divisions in Bohemian *Thysanopeltis* where their *clementinum* group corresponds to REED's *acanthopeltis* subgroup. According to their recent revision *Scutellum* (*Thysanopeltis*) *speciosus* comprises, beside the typical forms, 3 subspecies, namely *waldschmidti* KOENEN, *abreviatum* PRANTL, and *redividium* PRANTL. BARRANDE's *thysanopeltis* was considered by NOVAK (1890) and WOODWARD (1910) to be distinct from *speciosum*, but indistinct by REED. PRANTL synonymized a part of BARRANDE's *thysanopeltis* with *speciosum* and renamed the remainder or *thysanopeltis* proper as *Scutellum* (*Thysanopeltis*) *speciosum abreviatum*. The species and subspecies occur in Bohemia in the G_{α} to G_{γ} stages or Emsio-Couvinian. The other group of *Thysanopeltis* is represented in Bohemia solely by BARRANDE's *clementinum* from the G_{β} stage i. e. Daleji beds.

FRECH (1887) illustrated *speciosus* as a leading member of the Günsteröder Kalk (Unteres Mitteldevon) and the *Aphyllites fildelis* zone (Oberes Unterdevon). PRANTL referred WALDSCHMIDT's *thysanopeltis* from Wildungen to *speciosum waldschmidti* and MAUER's *thysanopeltis* ? from the Kalk von Griedenstein to *speciosum abreviatum*. In Eifel *Thysanopeltis acanthopeltis* SCHNUR occurs in the Eifelian Geeser Mergel of Gerolsteiner and Prumer Mulde together with *Cheirurus* (*Crotalocephalus*) *sternbergi* (RICHTER, 1921). Lately the synonymy of *Bronteus halli* WOODWARD from Gerolstein with *acanthopeltis* was readily confirmed by RICHTERS. *Bronteus laciniatum* SANDBERGER is a multispinose form of *Thysanopeltis* known from the Eifelian Wissbacher Schiefer. It is a question whether *Thysanopeltis barrandei* HÉBERT, 1855, from the Lower Devonian (? lower Coblenz stage) at Fourmies, Ardenne is another multispinose form, because according to BARRANDE (1857) it is analogous with *Dalmanites M'Coyi* BARRANDE.

Thysanopeltis magnispina MAILLIEUX, 1938, is a Couvinian member of Ardenne. On its pygidium 15 ribs are countable on the proximal side but 16 on the distal side probably because the post-axial rib is bifurcated. These radial ribs are generally independent from 24 spines, but evidently longer and less numerous than those of *speciosus*. These spines become longer from lateral to posterior gradually. Insofar as I am aware, five species of *Thysanopeltis* are reported from France as follows:

1. *Bronteus bureaui* TROMELIN et LEBESCONTE, 1876, from the Eifelian(?) at St. Huliend de Vouvantes, Bretagne, in the syncline of Angers in the Armorican massif. This is said to bear some resemblances with *thysanopeltis*, but in the former the spines are smaller and more numerous on the border than in the latter.
2. *Bronteus meridionalis* TROMELIN and GRASS, 1877, from Assise à *Spirifer cultrijugatus* (Eifelien) at Cabriéres, Hérault. Spines along the margin of the pygidium are numerous and extraordinarily minute and pleural ribs broader than those of *speciosum* and its varieties.
3. *Bronteus raphaeli* BARROIS, 1886, from Lower Devonian (between the Coblenzian and E stage) at Hont de Ver, Haute-Geronne, Pyrénes. The beds yield *Phacops fecundus* the occurrence of which is restricted in Bohemia and Germany to the Eifelian in addition to the top of the Coblenzian (GÜRICH, 1909). Therefore it is probable that the age of the beds is Eifelian. Contracted secondarily, the dorsal shield and accordingly the pygidium looks much broader than *speciosum*, but closely resembles that species in the mode of pleural

ribs and furrows and the size and density of the marginal spines.

4. *Bronteus trutati* BARROIS, 1886, from Lower Devonian (or Eifelian) at Hont de Bicoulous, Haut-Geronne, Pyrénes. Ribs on the pygidium are narrower than their flat interspaces and protruded beyond the raised marginal rim for some distance. The presence of a short secondary spine in each interval between two long primaries is the speciality.
5. *Bronteus rouvillei* FRECH, 1887, from the Schichten von Bataille in Cabriéres, Languedoc, which was considered late Middle Devonian, but could be Eifelian, because *Spirifer speciosus* was procured from the beds. Spines of the outer margin are very fine.

Thus, in Europe the *speciosus* group is well represented by many species, namely *laciniatum, barrandei, magnispina, meridionalis, raphaeli* and *rouvillei* beside *speciosus* and its 3 subspecies. Spines vary greatly in number and size, attaining about 60° at the maximum, but their size happens to be so small that they are shown only by high magnification, as in *meridionalis* for example. They are generally same in size on a pygidium, but become larger or longer backward in *magnispina*. The other group comprises *acanthopeltis, clementinum* and *trutati*, the last of which has two kinds of spines. The former group ranges from the Coblenzian to the Eifelian, while the latter is restricted in Europe to Eifelian or Couvinian.

In discussing the monophyletism of *Thysanopeltis*, RICHTERS emphasized that "Für die Zusammengehörigkeit der *acanthopeltis*-Gruppe mit der *speciosum*-Gruppe in einer Untergattung *Thysanopeltis* spricht der übereinstimmende Bau der Rippen. Bei beiden Gruppen sind die Rippen schmale, hohe, scharf begrenzte Leisten zwischen breiten Furchen, deren Boden oft zu Zwischenrippen aufgewölbt sind." They are of opinion that *Bronteus tellius* HALL and CLARKE, 1888, from the Upper Devonian Tully limestone of North America which has the cephalon and pygidium of the *costatum* group, should be excluded from *Thysanopeltis*.

As pointed out already by BARRANDE, the spines are different between the two groups. Namely, in the *acanthopeltis* group the spine is evidently a protuberance of a pleural rib or furrow whereas spines in the *speciosum* group are marginal modification regardless of the segmentation. In the number and size of spines *magnispina* and *trutati* are intermediate between the multi- and pauci-segmented groups, but if the relation of the spines to the segmentation is considered, there is no question about that *magnispina* and *trutati* belong respectively to the *speciosum* and *acanthopeltis* group, although they are aberrant forms in the groups.

The biological bearing of the spine must be greater in the *acanthopeltis* than in the *speciosum* group. As to the geological range in Europe the former is more restricted than the latter group. In the geographical distribution on the contrary the former is more extensive than the latter, because all of the Asiatic species belong to the *acanthopeltis* group, because the distinction of the two morphic groups bears such a geological and geographic bearing and because there is no intermediate form between them, the *acanthopeltis* group is distinguished here from the *speciosum* group as *Thysanopeltella*.

Beside the above mentioned there are four species of *Thysanopeltella* as follows:

1. *Bronteus yakovolevi* WEBER, 1923, from Middle Devonian in the Urals on the river Kamennaia Vogulka in the Lunivsk coal district. (N. N. YAKOVLEV collection).
2. *Bronteus tarak* WEBER, 1923, from Middle Devonian(?) black limestone in association with *Calymene* sp. in the district of Khodgent in the western part of the northern foreland of the Turkestan range. (Locs. 53 and 54, NEUMANN collection).
3. *Bronteus radiatus* WEBER, 1923, from Loc. 23, Turkestan (B. BOERLING collection). Because it is homonymous with *Bronteus radiatus* MÜNSTER, 1840, a new name, *Scutellum* (*Thysanopeltella*) *weberi* is proposed for it in honour of Dr. V. WEBER.
4. *Bronteus* (*Thysanopeltis*) *paucispinosa* OKUBO from Middle Devonian Nakazato series in

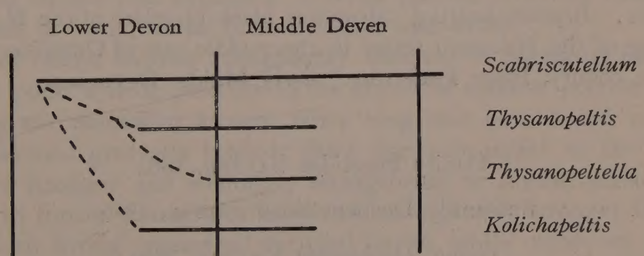
the Kitakami mountains, Japan.

It is a remarkable fact that the post-axial median rib is simple in the three species which Weber described. In *tarak* and *weberi* it is protruded into a spine, but in *yakovlevi* the rib is expanded in the posterior part where a pair of spines issue. In *acanthopeltis* on the other hand the rib is bifurcated, but there is a single spine which corresponds to the intercalated groove. *Pausispinosa* agrees with *clementinum* in the bifurcation of the median rib and eight pairs of spines each issuing from a pleural rib, and also in the straight articulating margin. In *paucispinosa*, however, the outline of the pygidum is subpentagonal and the margin is shorter than the breadth of the pygidium, while the outline is semiparabolic and the margin represents the maximum breadth in *clementinum*. *Trutati* is not essentially different from *clementinum*, if the short secondary spines are overlooked.

In *weberi* the spines are extraordinarily long, pleural lobes very narrow and the marginal rim is not well developed, but otherwise it is closely allied to *tarak*. Spines are short and subtriangular in *yakovlevi*, *acanthopeltis* and *paucispinosa*, and slender and fairly long in *clementinum* and also *trutati*. Interpleural furrows are narrower than ribs in *weberi* and *tarak*. They disagree with the diagnosis of *Thysanopeltis* s. l. above quoted, but morphic differences among these species of *Thysanopeltella* are gradual.

Nothing is known of the cephalon of *Thysanopeltella*. The cephalon of *Thysanopeltis magnispina*, though its illustration is obscure, appears to resemble that of *speciosum*, as far as can be judged from its description. The complete shield of *speciosum speciosum* shows its closer affinity with *Scutellum umbelliferum* than *S. planiferum* which Reed considered the ancester of *Thysanopeltis*. Richters are of opinion that *Thysanopeltis* branched off on one side and *Kolichapeltis* on the other through *Scutellum furciferum* from *Scabriscutellum* which was derived from *umbelliferum*. Before them Prantl and Přibyl suggested *furciferum* for the ancester of *Kolichapeltis* as well as *Thysanopeltis*.

In view of the close affiinity between *furciferum* and *paucispinosa* I am led to the contention that *Thysanopeltis* s. l. or at the least *Thysanopeltella* is located between *Scabriscutellum* and *Kolichapeltis*. Incidentally, *Scutellum* (*Kolichapeltis*) *angusticaudatus* (Etheridge and Mitchell), 1917, occurs in New South Wales, although no thysanopeltid is known from Australia and according to Richthers, *Goniopeltis* de Koninck from New South Wales which was thought a *Thysanopeltis* by Kayser is something else than the Scutelluidae. The phylogenetical relation of *Thysanopeltella* and its allied subgenera is shown below:



Scutellum (*Thysanopeltella*) *paucispinosum* (OKUBO)

Plate I, Figures 3a–b, 4

1951 *Bronteus* (*Thysanopeltis*) *paucispinosa* OKUBO, *Chikyu-kagaku, No. 4,* p. 137, pl. 1, figs. 5a-c.

Description:–Pygidium a little longer than broad, subpentagonal, but rounded in posterior, attaining to the maximum breadth at a little anterior to mid-length; anterior margin transversal, straight, nearly equal to a half of pygidium length, forming an angle of about 60 degrees at the lateral end. Axial lobe small, triangular and distinctly elevated above nearly flat pleural parts; trilobation very obscure; median part a little rising above its sides; no furrow among them. Facet in scaline trinagle, terminating at a spine; post-axial rib bifurcated in posterior third, each branch ending at a spine; 6 spines on a lateral margin between this and the first spine, each being issued from a pleural rib; pleural furrow a little narrower than rib and die out at a short distance inside of sinuation. Test apparently smooth.

Observation and measurement:—This species is represented by an external and internal mould of a pygidium which is 16 mm. long and its anterior margin 12 mm. wide. The axial lobe measures 3 mm. in length and 4 mm. in breadth. The right side of the pygidium is partly broken off, but if complete, it may be about 15 mm. wide. Because it appears to be secondarily deformed by lateral compression, the original breadth must have been greater than the above mentioned. The roof-shaped angulation of the ribs was probably produced by such compression.

Comparison:—OKUBO compared this species with *Bronteus halli* WOODWARD which is, as noted by RICHTER (1914, 56), identical with *Thysanopeltis acanthopeltis* (BARRANDE).

This is evidently a member of the *acanthopeltis* group, but quite different from *acanthopeltis*, *clementinum*, and *yakovlevi*, all having the maximum breadth on the anterior margin or near to it. In *tarak* and *weberi* the pygidium exclusive of spines becomes broadest at about the mid-length, but there is no antero-lateral facet as seen in this species, the post-axial rib simple and spines are longer in them. Spines are extraordinarily long in *weberi*. In spite of its name this species has eight pairs of spines.

In this species the trilobation of the axial lobe is quite obscure and the post-axial ridge extends from the lobe directly as in *Scutellum* (*Scutellum*) *furciferum* (BARRANDE) with which it agrees in many features so that it may be said spiniferous *furciferum*. *Kolichapeltis parabolium* is elongated and somewhat pentagonal in outline.

Occurrence:—Bryozoa-bearing calcareous black clayslate of the N_3 fossil beds in the upper part of the Nakazato series in the middle part of Omori-zawa, Hikoroichi village, Kesen county, Iwate Prefecture. Early Middle Devonian.

Family Proetidae SALTER, 1862

Subfamily Dechenellinae PŘIBYL, 1946

Genus *Dechenella* KAYSER, 1880

Subgenus *Dechenella* KAYSER, 1880

Type:—*Phillipsia verneuili* BARRANDE.

Dechenella was divided by R. RICHTER in 1912, into *Eudechenlla*, *Paradechenella*

and *Basidechenella*, where the first was later synonymized with subgenus *Dechenella* by R. and E. RICHTER. Even with the cranidium only, true *Dechenella* can readily be distinguished from the two other subgenera by its posterior expansion of the glabella, development of the last furrow on the glabella and the erected frontal border. According to RICHTERS (1950), it comprises the followings:

Archegonus aequalis STEINIGER, 1852 (=*verneuili* BARRANDE)
Dechenella (*Euechenella*) *burmeisteri* RICHTER, 1912, from Westfalen
Dechenella (*Dechenella*) *gigouti*, RICHTER, 1950, from Morocco
Dechenella (*Eudechenella*) *granulata*, RICHTHR, 1912, from Eifel
Dechenella polonica GÜRICH, 1896, from Polonisches Mittelgebirge
Dechenella rittergensis ZIMMERMANN, 1892, from Mähren
Dechenella romanovski TSCHERNYSCHEW, 1887, from Ural.
Dechenella setosa WHILDBORNE, 1889, from Devonshire.
Dechenella (*Dechenella*) *struvei* RICHTERS, 1900, from Hillesheimer Mulde.

RICHTERS noted the possible reference of three additional species to the same subgenus as follows:

Proetus haldemanni HALL, 1888, from New York.
Proetus nortoni WALTER, 1920, from Iowa.
Dechenella sp. aff. *D. macrocephala* HALL by PATTE, 1929, from Tsche Ts'ouen near Amitcheou, Yunnan.

They however, excluded *Dechenella* (*Dechenella*) *mackayi* ALLAN from New Zealand from *Dechnella*. Finally, *Dechenella minima* OKUBO is diagnostic of *Dechenella* of *Dechenella*.

Distribution:—Givetian of Europe (Bohemia, Harz, Rhineland, Devonshire, Poland and Ural) and North Africa (Morocco); North America (New York and Iowa) and Eastern Asia, (Yunnan and Japan).

Dechenela (*Dechenella*) *minima* OKUBO

Plate I, Figures 1a-b, 2a-b

1950 *Dechenella minuma* OBUBO, *Chikyu-Kagaku, No. 4*, p. 28, pl. 1, figs. 6a-c.

Description:—Cranidium broad, its breadth measured through palpebral lobes a little longer than its length; glabella very large, subovate, so long as to reach the frontal groove, abruptly and strongly swelling above cheeks, giving somewhat bulbous appearance, more or less contracted at the mid-length of glabella exclusive of neck ring and thence well expanded; anterior portion relatively broad for genus and well rounded in front; dorsal furrow narrow and weak.

Four pairs of lateral furrows considerably different in strength; first furrow almost a pit at a point a little posterior to the middle of anterior portion of glabella; second one diagonal, somewhat arcuate, fairly long and pronounced near glabellar margin, but weakened gradually inward; third one subparallel to the preceding, a little longer and stronger and seemingly strengthened at a short distance from the inner end; fourth furrow nearly parallel to and incomparably stronger than the third and confluent with strong transversal occipital furrow, while others are disconnected on axial portion.

Frontal lobe a little longer than lateral lobes which are in turn similar in length; last lobe in particular depressed and isolated from main body of glabella by the fourth furrow, forming an elliptical embossment; axial part of the third lobe

somewhat protruded back between the pair of such bosses and slightly hanging over occipital furrow; occipital ring broad.

Fixed cheek very narrow; palpebral lobe presumably large; palpebral furrow obscure. Frontal border roof-shaped, more steeply inclined forward than backward; facial sutures apparently diagonal and intramarginal on two sides of frontal border.

Observation:—This species is represented by a cranidium of which fixed cheeks are poorly preserved. The axial part of the glabella proper may be more pointed back than illustrated, if the part is undamaged. The occipital ring is strongly bent down on the two sides. There the basal lobe on the right side is protruded above the dorsal furrow and the postero-inner corner of the cheeck subvertical; there is no tubercle at this place as often seen in this genus. The frontal border has no median casp. Because the test is oxydized, it is difficult to say about texture, but the frontal lobe which is least altered, appears to be roughened by granules.

Comparison:—As to *Trilobites verticalis* BURMEISTER, 1843, to which OKUBO compared this species, RICHTER gives a mention that "*Mischgebilde mit einem nicht mehr bestimmbaren Dechenellenbestandteil.*" *D.* (*E.*) *burmeisteri* was proposed by him for *verticalis* by SCHULTER (1880), KAYSER (1880) and OEHLERT (1885).

In the outline of the glabella and lack of the frontal limb this agrees with *polonica*, but differs in the strength and course of lateral furrows and other features. With regard to these furrows it is more allied to *verneuili*, *burmeisteri* and *struvei*, but the glabella is broader and a narrow space always present between the glabella and frontal border. The last lateral furrow joins with the occipital one in *struvei* and *burmeisteri* and the axial part is pointed back in *burmeisteri*, but not so protruded as in this. In that species the occipital furrow is arched, instead of transversal, and provided with a tubercle near the lateral end.

Occurrence:—Nakazato series in the middle part of Higuchizawa, Hikoroichi-village, Kesen County, Iwate Prefecture. The trilobites suggests that this horizon is higher than that of *Thysanopeltella minima*.

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Synoptic List of *Thysanopeltis* and *Thysanopeltella.*

Thysanopeltis speciosa HAWLE and CORDA, 1847 ······ *Thysanopeltis*
Bronteus thysanopeltis BARRANDE, 1852 ······ *Thysanopeltis*
Bronteus acanthopeltis BARRANDE, 1852 ······ *Thysanopeltis*
Bronteus clementinum BARRANDE, 1852 ······ *Thysanopeltella*
Bronteus barrandei HÉBERT, 1800 ······? *Thysanopeltis*
Goldeus bureaui TROMELIN-LEBESCONTE, 1876 ······ *Thysanopeltis*
Bronteus meridionalis TROMELIN-GRASS, 1876 ······ *Thysanopeltis*
Bronteus waldschmidti KOENEN, 1882 ······ *Scutellum* (*Thysanopeltis*) *speciosum waldschmidti*
Bronteus raphaeli BARROIS, 1886 ······ *Thysanopeltis*
Bronteus trutati BARROIS, 1886 ······ *Thysanopeltella*
Bronteus rouvillei FRECH, 1887 ······ *Thysanopeltis*
Bronteus laciniatum SANDBERGER, 1891 ······ *Thysanopeltis*
Bronteus halli WOODWARD, 1910 ······ *Scutellum* (*Thysanopeltella*) *acanthopeltis*
Bronteus tarak WEBER, 1923 ······ *Thysanopeltella*
Bronteus yakovlevi WEBER, 1923 ······ *Thysanopeltella*
Bronteus radiatus WEBER, 1923, non MÜNSTER, 1840 ······ *Scutellum* (*Thysanopeltella*) *weberi*
Thysanopeltis magnispina MAILLIEUX, 1938 ······ *Thysanopeltis*
Scutellum (*Thysanopeltis*) *speciosum revidium* PRANTL, 1949 ······ *Thysanopeltis*
Scutellum (*Thysanopeltis*) *speciosum abreviatum* PRANTL, 1949 ······ *Thysanopeltis*
Bronteus (*Thysanopeltis*) *paucispinosa* OKUBO, 1951 ······ *Thysanopeltella*
Scutellum (*Thysanopeltella*) *weberi* KOBAYASHI, 1957 ······ *Thysanopeltella*

T. Kobayashi

Notes on two Devonian Trilobites from the Kitakami Mountains in Japan

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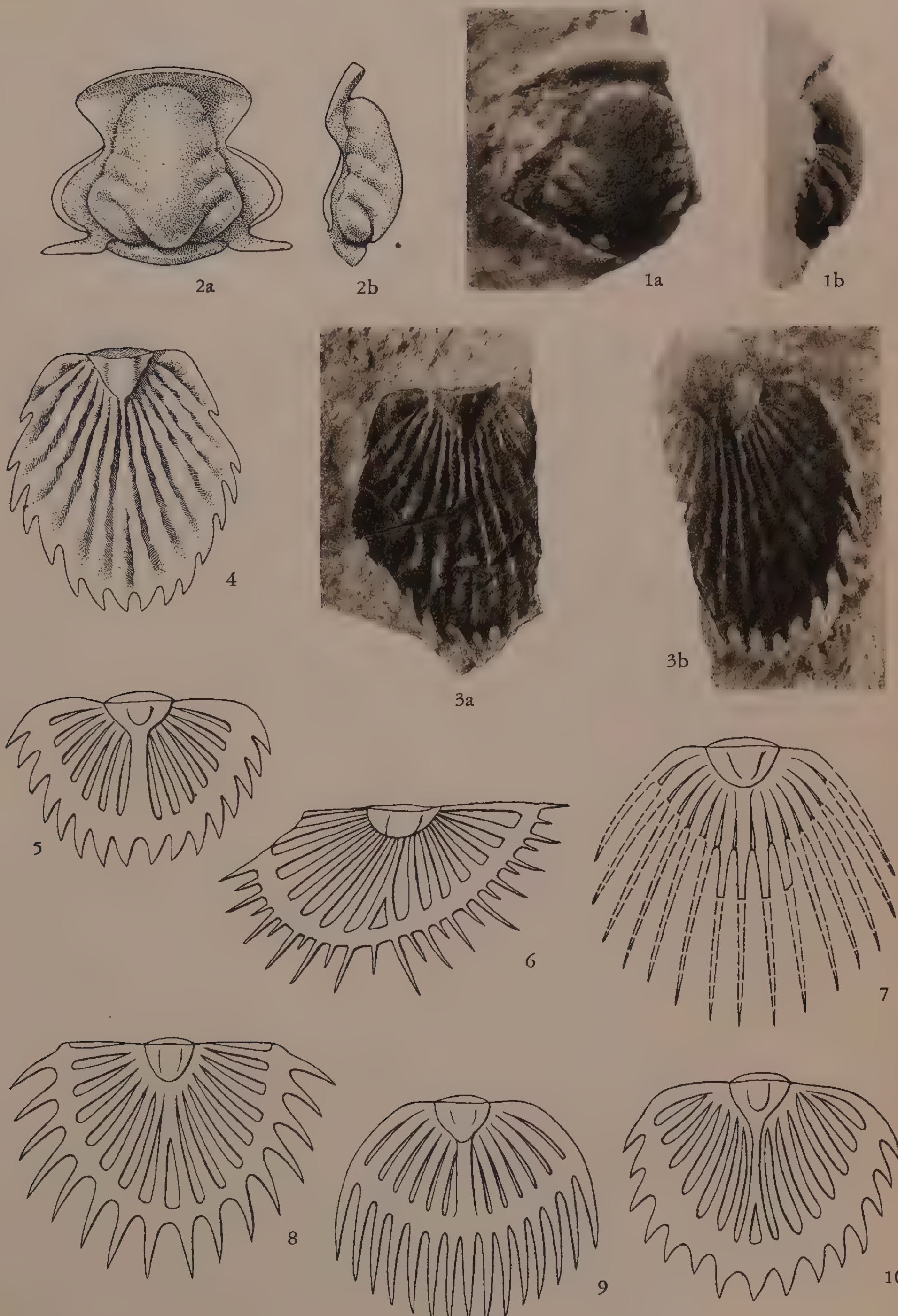
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STUDIES ON THE OSTRACODA FROM JAPAN

III. Subfamilies Cytherurinae G. W. Müller (emend. G. O. Sars 1925) and Cytheropterinae n. subfam.

By

Tetsuro Hanai

With 3 Plates

Abstract

Cytherurine Ostracoda can be classified into the following groups and subgroups on the basis of hinge structure: 1) *Cytherura* group (*Cytherura* G. O. Sars, *Hemicytherura* Elofson, *Tetracytherura* Ruggieri, *Microcytherura* G. M. Müller, and *Howeina*, n. gen.); 2) *Cytheropteron* group: 2a) *Cytheropteron* subgroup (*Cytheropteron* G. O. Sars, *Aversovalva* Hornibrook, *Kangarina* Coryell and Fields, and *Kobayashiina*, n. gen.), 2b) *Paracytheridea* subgroup (*Paracytheridea* G. W. Müller, *Paracytheropteron* Ruggieri, and *Pseudocytherura* Dubowsky); 3) *Eocytheropteron* group (*Eocytheropteron* Alexander, and *Budaia* Mehes); 4) genera of uncertain classificatory position (*Looneyella* Peck, *Orthonotacythere* Alexander, *Eucytherura* G. W. Müller, and *Paradoxorhyncha* Chapman). The *Cytherura* group and the first *Cytheropteron* subgroup are here described as subfamilies Cytherurinae G. W. Müller, 1894 (emend. Sars, 1925) and Cytheropterinae, n. subfam., respectively. The *Paracytheridea* subgroup is of uncertain status. The *Eocytheropteron* group, however, might have subfamily rank. In this paper, six species of *Cytherura*, one species of *Howeina*, n. gen., three species of *Hemicytherura*, four species of *Cytheropteron* and one species of *Kobayashiina*, n. gen., are described from Japan.

Contents

Introduction

The cytherurine Ostracoda are perhaps the most common Ostracoda in the world. They occur abundantly in the sea surrounding Japan, but have not been studied previously in detail owing to their minute size. From this area *Cytheropteron videns* G. M. Müller and *Cytheropteron mucronalatum* Brady have been reported by Kajiyama (1913) and Brady (1880), respectively. The former species is actually a species of *Hemicytherura*, here described as *Hemicytherura kajiyamai* Hanai, n. sp.; the latter actually belongs to the genus *Brachycythere*.

[1]Received May 10, 1957.

Our knowledge of Ostracoda is not great enough to classify and define the cytherurine Ostracoda with much certainty. In this paper, cytherurine Ostracoda are provisionally subdivided into groups which probably have subfamily rank. In this paper, five genera are described from Japan. The genera *Cytherura*, *Howeina*, n. gen., and *Hemicytherura* belong to the subfamily Cytherurinae G. W. Müller (emend. G. O. Sars, 1925), and the genera *Cytheropteron* and *Kobayashiina*, n. gen., belong to the subfamily Cytheropterinae Hanai, n. subfam.

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Remarks on classification of cytherurine Ostracoda

Until G. O. Sars (1865) established the genera *Cytherura* and *Cytheropteron* as genera of the family Cytheridae, cytherurine Ostracoda had been included in the genus *Cythere*. In 1894 G. W. Müller proposed the subfamily Cytherurinae and included three genera, *Cytherura*, *Cytheropteron* and *Eucytherura*. In 1925 G. O. Sars restricted the subfamily Cytherurinae to "the Ostracoda chiefly referable to the genus *Cytherura*". He included the genus *Cytheropteron* in his subfamily Loxoconchinae. After this, confusion of the classificatory position of the genus *Cytheropteron* and its allies arose. Some authors followed G. M. Müller (e. g. Klie, 1938) and some followed G. O. Sars' opinion (e. g. Doeglas, 1931, Blake, 1933). In 1941 Elofson tabulated the anatomical characters of *Cytherura*, *Cytheropteron*, and *Loxoconcha* and concluded that "Eine sorgfaltige Untersuchung ergibt bald, dass G. W. Müller mit seiner Ansicht ganz recht haben muss. Die Eigenschaften, welche die beiden Gattungen *Cytherura* und *Cytheropteron* gemeinsam haben, sind namlich sowohl quantitative den *Cytheropteron* und *Loxoconcha* gemeinsamen weit überlegen". In spite of Elofson's clear explanation, the confusion of the classificatory position of the genus *Cytheropteron* has continued (e. g. Van den Bold, 1946, Bowen, 1953, Munsey, 1953, Apostolescu, 1955). So far as the hinge structure is concerned, Loxoconchinae are distinctly different from cytherurine Ostracoda.

The carapace of cytherurine Ostracoda is small, usually sculptured. Wing-like lateral expansions are usually characteristic of this group of Ostracoda, but are obscure in some species of subfamily Cytherurinae G. W. Müller, 1894 (emend. Sars,

1925) Posterior caudal process is usually prominent. Right valve is usually larger than the left, especially along the dorsal margin. Hinge is merodont, and classifiable into two types on the basis of crenulations. The first type is characterized by the right valve with terminal knob-like teeth, one or rarely more than two at each end of the long blade-like ridge of the inner lamella, but usually small and indistinct in subfamily Cytherurinae. In subfamily Cytheropterinae HANAI, n. subfam., teeth of right valve are strong and crenulate or consisting of a series of knob-like teeth; blade-like edge of inner lamella is usually not well developed. The first type is here called *Cytherura* type and the second is called *Cytheropteron* type. Hingement is also classifiable on the basis of hinge and flange arrangement: 1) flange strongly developed and overhanging the actual hinge element of right valve, but not reaching the terminal teeth so as to form a furrow between the terminal teeth and the overhanging flange. This type hingement is usually arched or if straight it is short. It is here called *arched* or *short type*. 2) flange is not greatly overhanging the actual hingement and reaching the terminal teeth. This type of hingement is usually straight and long. The crenulate groove between the terminal teeth is well developed. This second type is here called *long straight* type. The marginal area is extremely well developed in some of the subfamily Cytherurinae, with the inner margin coinciding with the line of concrescence and curving forward in the back half of the carapace. The radial pore canals tend to be grouped in this type of marginal area. In the subfamily Cytheropterinae usually the development of the marginal area is moderate and there is a vestibule. The radial pore canals are usually simple. However, in both cases the number of radial pore canals is small. Adductor muscle scars are all nearly the same, usually arranged in a posterior vertical row of four scars and one or two anterior scars. Eye spots are rather distinct in the subfamily Cytherurinae, but are not distinct in the subfamily Cytheropterinae. However, they are distinct in *Paracytheridea* and its allies.

Although the classification of the cytherurine Ostracoda is of uncertain status, the following genera and subgenera have been assigned to the cytherurine Ostracoda, or are considered to be closely related to them.

1. *Cytherura* group=Subfamily Cytherurinae G. W. MÜLLER,, 1894 (emend. SARS, 1925)

Hinge short or arched and of *Cytherura* type.

Cytherura G. O. SARS, 1865 (1866) pp. 69, 70; type species: *Cythere gibba* O. F. MÜLLER, 1785, p. 66, designated by BRADY, 1868, p. 439.

Hemicytherura ELOFSON, 1941, p. 314; type species: *Cythere cellulosa* NORMAN, 1865, p. 22, by original designation. The genus was proposed by ELOFSON (1941) as a subgenus of *Cytheropteron*. This group of Ostracoda corresponds also to the *Cytheropteron videns* group which was originally included in *Cythere* and later in *Cytherura*, and was separated from *Cytherura* and included in *Cytheropteron* by G. W. MÜLLER in 1894. Recently RUGGIERI, 1952, considered *Hemicytherura* a subgenus of *Cytherura* instead of a subgenus of *Cytheropteron*, because of: 1) the clear eye spots on the carapace, 2) the *Cytherura* type hinge line, and 3) the coincidence of the inner margin with the line of concrescence. In the same year, 1952, HORNIBROOK raised this subgenus to generic rank.

Tetracytherura RUGGIERI, 1952, p. 86; type species: *Cytheridea angulosa* SEGUENZA, 1880, p. 363.

Microcytherura G. W. MÜLLER, 1894, p. 383; type species: *Microcytherura nigrescens* G. W. MÜLLER, 1894. As to the systematic position of this genus, KLIE (1938) stated as follows: "G. W. MÜLLER hat 1894 für eine Art des Golfs von Neapel, die in der Farbe und in der Schalenform an die Gattung *Cytherura* erinnert, das Gattung *Microcytherura* begrundet, das bis heute nur durch die dortige Art *nigrescens* vertreten war. Der Gattungsname konnte zu dem Missverstandnis Veranlassung geben, dass *Microcytherura* mit *Cytherura* nahe verwandt sei, etwa wie *Microxestoleberis* mit *Xestoleberis*. Das ist jedoch keineswegs der Fall. *Microcytherura* gehört vielmehr zweifellos zur Unterfamilie Cytherinae, der gegenüber die Cytherurinae eine selbstandige Unterfamilie bilden." However, in this paper *Microcytherura* is provisionally placed in the subfamily Cytherurinae. I have not had available for study the type specimens of this genus.

Howeina HANAI, n. gen.; type species: *Howeina camptocytheroidea* HANAI, n. sp.

2. *Cytheropteron* group

2a. *Cytheropteron* subgroup=Subfamily Cytheropterinae Hanai, n. subfam.

Hinge arched and of *Cytheropteron* type.

Cytheropteron G. O. SARS, 1865 (1866), pp. 79, 80; type species: *Cytheropteron convexum* (BAIRD) by G. O. SARS on mistaken identification,=*Cythere latissima* NORMAN, 1865, by BRADY, 1868, p. 448, by BARDY and NORMAN, 1889, p. 207, and by G. O. SARS, 1926, p. 223.

Aversovalva HORNIBROOK, 1952, p. 57; type species: *Cytheropteron* (*Aversovalva*) *aureum* HORNIBROOK, 1952, by original designation. This snbgenus of *Cytheropteron* has the left valve larger than the right owing to the strong development of the groove above the median bar of the left valve for accomodating the dorsal edge of the right valve. This subgenus is the only one in the Cytheropterinae which has the right valve larger than the left.

Kangarina CORYELL and FIELDS, 1937, p. 12; type species: *Kangarina quellita* CORYELL and FIELDS, 1937, by original designation. This genus from the Miocene of Panama was originaly included in the subfamily Loxoconchinae. This assignment was followed by VAN DEN BOLD (1946). However, RUGGIERI (1952) considered it a subgenus of *Cytheropteron* because of the absence of eye spots and its habitat.

Kobayashiina HANAI, n. gen.; type species: *Kobayashiina hyalinosa* HANAI, n. sp.

2b. *Paracytheridea* subgroup

Hinge straight and of *Cytheropteron* type.

Paracytheridea G. W. MÜLLER, 1894, p. 340; type species: *Cytheropteron bovettensis* SEGUENZA, 1880. This genus was placed by VAN DEN BOLD, 1946, in the Cytherideinae.

Paracytheropteron RUGGIERI, 1952, p. 78, 79; type species: *Cytheropteron calcaratum* SEGUENZA, 1880. This subgenus of *Paracytheridea* has a carapace whose shape is intermediate between *Paracytheridea* and*Cytherura*, but has a *Cytheropteron* type hinge and is considered intermediate between *Paracytheridea* and *Cytheropteron* by RUGGIERI (1952). It is noteworthy that he compared his *Paracytheropteron* with *Lophocythere* of the Progonocytherinae.

Pseudocytherura DUBOWSKY, 1939, pp. 12–16; type species: *Pseudocytherura pontica* DUBOWSKY, 1939. As to the systematic positson of this genus, DUBOWSKY stated as follows: "Die allgemeine Schalenform, die Strukture des Innerandes, die

Eigenschaften der Maxilla und der Furca stellt diese neue Gattung den von G. W. Müller in Subfam. Cytherurinae vereinigten Gattung nahe. Die Struktur der I Antenne aber, die 4-gliedrigkeit der II-ten, wie die Abwesenheit der II-ten ventralen (hintern) Borste am Basalglied des I Bein-paares unterscheidet scharf *Pseudocytherura* von dieser Gruppe, stellt sie zur Gattung *Paracytheridea* nahe und verbindet durch Übergange Cytherurinae (im Sinne von G. W. Müller) mit den übrigen Cytheridae."

3. *Eocytheropteron* group

Although many species of this group have no trace of wing-like lateral expansions, they have a close resemblance in outline to the *Cytheropteron* group, especially in the shape of the caudal process, however the hinge structure of this group is quite dissimilar to that of the *Cytheropteron* group in the following characters:

1) there is development of a flange above the hinge element of the right valve, and the overhanging flange above the hinge element of the left valve causes the lapping of the left valve over the right along the dorsal margin.

2) the crenulations are comb-like instead of the pit-and-knob type. Differentiation of the terminal teeth from the median element is somewhat indistinct, because the intervals between crenulatians are almost constant. However, the crenulations in the left valve are deepened and are overhung greatly by the flange along the anterior and posterior portions of the hingement, where the individual notch of the crenulations is more elongate vertically than those of the median portion. The right valve hingement is complementary. The hinge structure described above is quite different from those of other cytherurine Ostracoda. Perhaps the following genera will form a new group of Ostracoda with subfamily rank.

Eocytheropteron Alexander, 1933, p. 195; type species: *Cytheropteron bilobatum* Alexander, 1929, by original designation. This genus was originally described by Alexander, 1933, as a subgenus of *Cytheropteron*. This assignment has been followed by most workers. Independently from Alexander's work, Broussard (1932 Unpub. MS) studied this genus and recognized it as a genus of uncertain systematic position.

Budaia Méhes, 1941, p. 67; type species: *Budaia prima* Méhes, 1941, by original designation.

4. Genera of uncertain classificatory position

Eucytherura G. W. Müller, 1894, p. 305; type species: *Cythere complexa* Brady, 1867, p. 210, designated by Alexander, 1936, p. 692. This genus has been included in the subfamily Cytherurinae since the original description, and has been reviewed thoroughly by Weingeist (1949).

Orthonotacythere Alexander, 1933, pp. 199, 200; type species: *Cytheridea hannai* Israelsky, 1929, p. 12, by original designation. This genus was originally compared with *Monoceratina* and was believed by Alexander to have been derived from *Monoceratina*. Martin (1940) classified this genus in the subfamily Cytherurinae, and later Van den Bold (1946) placed it in the subfamily Loxoconchinae, in which he also included *Cytheropteron* and its allies.

Looneyella Peck, 1951, pp. 575, 576; type species: *Cythere monticula* Jones, by original designation. Peck (1951) compared this genus to the Upper Jurassic genus *Hutsonia* Swain; he stated that this genus may have developed from *Hutsonia*.

Paradoxorhyncha Chapman, 1904, p. 202; type species: *Paradoxorhyncha foveolata* Chapman, by original designation. This genus is of uncertain status.

Repositories of Type Specimens

All holotypes and some paratypes are deposited in the type collection of the Geological Institute, University of Tokyo, Tokyo, Japan, and the other paratypes are deposited in the H. V. Howe Collection, School of Geology, Louisiana State University, Baton Rouge, Louisiana, U. S. A.

Systematic descriptions

Family Cytheridae Baird, 1850

Subfamily Cytherurinae G. W. Müller, 1894 (emend. Sars, 1925)

1894 Cytherurinae G. W. Müller (part.) p. 286.
1925 —— G. O. Sars, p. 199.
1938 —— Klie, (part.) p. 187.
1941 —— Elofson, (part.) pp. 304, 305.
1955 —— Swain, (part.) p. 626.

Type genus: *Cytherura* G. O. Sars, 1865.

Diagnosis: Carapace small and broad, with posterior caudal extension. Wing-like process is not prominent. Surface weakly to strongly sculptured. Right valve larger than the left, overlaps the left especially along the dorsal margin. Hinge, *Cytherura* type, arched or straight but short. Area of concrescence very broad. Inner margin is in some cases parallel to outer margin, in others irregular and making modified S-shape in posterior region. Vestibule not present. Radial pore canals few, usually long, curved and tending to be grouped. Normal pore canals few and scattered. Adductor muscle scar consists of four posterior vertical scars and one anterior scar. Eye spot usnally distinct.

Remarks: In this paper, the writer followed G. O. Sars' opinion on subfamily Cytherurinae, restricting it to comprise a number of rather small cytherid Ostracoda " chiefly referable to the genus *Cytherura* G. O. Sars". This subfamily includes the following genera:

Cytherura G. O. Sars, 1865 (1866).
Hemicytherura Elofson, 1941.
Howeina Hanai, n. gen.
?*Tetracytherura* Ruggieri, 1952: This genus differs from *Cytherura* in having a distinct anterior vestibule.
?*Microcytherura* G. W. Müller, 1894: Klie's opinion on the systematic position of this genus was quoted on page 14.

Genus *Cytherura* G. O. Sars, 1865 (1866)

Cytherura auct. (part.)

1865 (1866) *Cytherura* G. O. Sars, pp. 69, 70.
1868 —— Brady, Int. Obs., p. 124.
1868 —— Brady, Mon., p. 439. (Designation of type species).
1874 —— Brady, Crosskey and Robertson, pp 191, 192.
1878 —— Brady, p. 401.
1880 —— Brady, p. 130.
1888 —— Dahl, p. 626.
1889 —— Brady and Norman, p. 190.
1894 —— Lienenklaus, p. 238.

1894	——	G. W. MÜLLER, p. 287.
1900	——	NAMIAS, p. 109.
1900	——	LIENENKLAUS, p. 539.
1905	——	LIENENKLAUS, p. 54.
1912	——	G. W. MÜLLER, p. 263.
1925	——	G. O. SARS, p. 199.
1928	——	NEVIANI, p. 32.
1936	——	ALEXANDER, p. 690.
1936	——	VAN VEEN, p. 21.
1938	——	KLIE, Tierwelt, pp. 187, 188.
1944	——	EDWARDS, p. 525.
1946	——	VAN DEN BOLD, p. 34.
1946	——	STEPHENSON, p. 316.
1948	——	KINGMA, p. 33.
1952	——	HORNIBROOK, p. 50.
1953	——	RUGGIERI, pp. 116–118.
1955	——	SWAIN, p. 626.

Type species: *Cythere gibba* O. F. MÜLLER, 1785.

Diagnosis: Cytherurinae having small and subquadrate carapace with distinct caudal process. Hinge *Cytherura* type, arched or straight but short; anterior and posterior teeth knob-like and single or rarely paired at each end of hinge at the termination of the blade-like ridge of the inner lamella of right valve. Marginal area well-developed and irregular. Inner margin makes S-shape in the posterior region. Other carapace structures are the same as those mentioned in diagnosis of the subfamily.

Description: Shape and ornamentation variable. Wing-like lateral expansion not always distinct. Posterior caudal process distinct. Nature of radial pore canals, normal pore canals, adductor muscle scar and eye spot the same as in the diagnosis of the subfamily. Usually three radial pore canals in posterior caudal area. Right valve hingement has one, or rarely two, terminal teeth which are knob-like but not very distinct at each end of blade-like outer edge of inner lamella. Flange developed strongly and projecting over actual hinge element, but not quite reaching terminal teeth. Hinge of left valve has a median bar and terminal sockets. The bar usually crenulate and thickened so as to form knob-like projections in its terminal parts; bar fits into groove or trace of groove just under overhanging flange and between terminal teeth of right valve. Groove usually crenulate and sometimes having socket-like pits in terminal parts. Flange developed over hinge element immediately above anterior and posterior terminal sockets of left valve; the flange fits furrow between terminal teeth and overhanging flange of right valve. Sometimes furrow continues a long distance between posterior blade-like inner lamella and overhanging flange. Median bar usually slightly projecting over flange in dorsal view.

Remarks: G. W. MÜLLER (1894) divided the genus *Cytherura* into two groups: 1) carapace with wing-like process, 2) carapace without wing-like process. Furthermore, he divided the first group into two subgroups: 1a) carapace without any indication of longitudinal ridges over the wings, 1b) carapace with distinct longitudinal ridges over the wings. Among Japanese species, *Cytherura miurensis* HANAI, n. sp., and *C. tetragona* HANAI, n. sp., might belong to the second group of G. W. MÜLLER. The other Japanese *Cytherura* do not belong to any of the groups or subgroups of G. W. MÜLLER, and may form a new group of *Cytherura* which is characterized by thick undulated ridges, perhaps exemplified by *Cytherura undata*

G. O. SARS. This group of *Cytherura* usually has a quadrate outline and rather thick shell.

Cytherura tetragona HANAI, n. sp.

Plate II, figures 5 a, b.

Description: Carapace sub-tetragonal in lateral outline, highest at anterior cardinal angle. Anterior margin obliquely rounded, dorsal and ventral margins straight, nearly parallel to each other, posterior caudal process inconspicuous, blunt, and located at mid-height, pointed posteriorly. Surface ornamented by dense, fine punctations and fine ridges. Punctations somewhat coarse in central area. Ridges prominent in ventral area where several long and fine ridges run parallel to ventral margin. In anterior area, a fine ridge runs along anterior margin and four to five ridges run from adductor muscle scar area to anterior margin more or less radially. Posterocentral surface rather inflated and lacking fine ridges. Eye spot distinct. Hinge straight, arrangement typical of genus. Anterior tooth of right valve represented by knob-like projection. Posterior tooth not well-defined from the flange-like ridge along posterior margin. Median groove socketed in its anterior and posterior parts. In middle part, groove becomes obscure. Hingement of the left valve complementary. Marginal area extremely broad, a character typical of this genus. Adductor muscle scar typical of genus with an additional three scars above and two scars below. Anterior view subtriangular with more or less flat ventral surface. Dorsal view oblong with more or less sharp anterior and posterior points.

Dimensions: Holotype (complete carapace) length 0.44 mm., height 0.22 mm., thickness 0.18 mm.; paratype (complete carapace) length 0.36 mm., height 0.18 mm., thickness 0.15 mm.

Occurrence: The holotype was obtained from Recent beach sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture. The paratype was obtained from a beach sand from the shore of Kashiwara, about 200 meters S. E. of Dozanto-to, near Yamaga, Ashiya-machi, Onga-gun, Fukuoka Prefecture, where the species is rare.

Remarks: Inside views of this species show clearly that the anterior and posterior teeth of the right valve are modifications of the edge of the inner lamella, and the flange over the hingement is a modification of the outer lamella. This species has some resemblance to *Cytherura simplex* BRADY and NORMAN.

Cytherura miurensis HANAI, n. sp.

Plate II, figures 4 a, b; text-figures 4a, b.

Description: Carapace every thin and subtransparent, oblong in lateral outline. Anterior margin broadly rounded, dorsal margin arched and highest at middle, ventral margin nearly straight, sinuous in anterior part; posterior caudal process prominent, more or less upturned and acute. Valves rather tumid with a very shallow sulcus-like depression in central part. Ventrolateral area of valves hang down slightly so as to make ventral area flat. Surface ornamented by fine ridges running more or less longitudinally. Vertical ridges partially developed between longitudinal ridges so as to form a "cobweb" pattern. Longitudinal ridges prominent in ventral area. Between ridges surface minutely punctate. Hinge arrangement typical of genus. Anterior tooth of right valve represented by a series of about three tiny,

rounded teeth at termination of ridged selvage. Median element smooth. Posterior tooth represented by a series of one or two tiny, rounded projecting teeth at termination of long ridged selvage. Hingement of left valve is complementary. Adductor muscle scar at central area where external median sulcus swells internally. Details of scars not observable. Marginal area developed anteriorly and posteriorly; line of concrescence coincides with inner margin; at anteroventral area inner margin of the inner lamella has a small but characteristic sinuation. Posterior marginal area broad, its inner margin S-shaped starting at posterior end of the hingement, making a convex curve toward center in its upper two-thirds and strongly concave in lower one-third, and reaching near the middle of ventral margin of carapace. Radial pore canals have a tendency to be grouped, especially along anteroventral margin, and are prominent in posteroventral and posterodorsal areas. In some specimens which have a rather narrow anterior margin and less inflated posterocentral area, posterior marginal area becomes obscure. In dorsal view, carapace oblong oval, thickest posteriorly; posterior pointed. In anterior view, carapace ovate.

Dimensions: Holotype (complete carapace) length 0.51 mm., height 0.23 mm., thickness 0.22 m.; paratype (complete carapace) length 0.53 mm., height 0.28 mm., thickness 0.24 mm.

Occurrence: All type specimens were collected from Recent beach sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture.

Remarks: Two forms are recognizable in this species. One has an inflated posterocentral area and is rather elongate in shape. This difference is especially prominent in dorsal view. At first I believed that the inflated form might be a female; however, according to G. O. Sars (1925) the male form of *Cytherura intumescens* has a more inflated posterocentral surface than the female form. Perhaps this is due to the very large copulative appendages.

Cytherura skippa Hanai, n. sp.

Plate II, figures 6 a, b.

Description: Carapace elongate, oblang; anterior margin rounded with about five small crenulations; dorsal and ventral margins long, parallel; posterior caudal process prominent, located above mid-height and upturned. Surface ornamented by primary strong and straight ridges. Anterior dorsal and ventral marginal ridges prominent. Longitudinal ridge running posteriorly from middle of anterior margin obscured in central area where longitudinal ridge is broken into reticulate area. In posterodorsal area ridges make a prominent triangular pattern. Open areas not smooth. Hinge long for subfamily Cytherurinae, and straight. Anterior and posterior teeth of right valve not well developed; median element crenulate, especially in posterior half. Character of marginal area typical of genus. Adductor muscle scar not observable. In anterior view, carapace sub-hexagonal with flat dorsal and ventral surfaces. In dorsal view, carapace oblong with sharp anterior end and prominent handle-like posterior projection of caudal process.

Dimensions: Holotype (complete carapace) length 0.32 mm., height 0.14 mm., thickness 0.14 mm.

Occurrence: The type specimen was obtained from Recent beach sand from Toura, Hamazaki-mura, Kamo-gun, Shizuoka Prefecture, where the species is rare.

Remarks: The New Zealand species described by Hornibrook as *Cytherura costellata* Brady, which is somewhat different from Brady's original figure in the

Challenger Report, has close relationship to this species. However, the surface ornamentation is not similar to *Cytherura costellata* of Hornibrook, especially in its posterior area.

Cytherura quadrata Hanai, n. sp.

Plate III, figures 1 a, b; text-figures 2a, b.

Description: Carapace rather thick box-shaped, a little higher anteriorly than posteriorly. Anterior margin obliquely rounded with about five small crenulations on anteroventral narrowly rounded margin; dorsal and ventral margins nearly straight, almost parallel; posterior caudal process short and blunt, located at mid-height, and pointed posteriorly. Surface ornamented by strong ridges. Ventral ridge prominent, starting at lower part of anterior marginal ridge running posteriorly, arching at middle, and very slightly obscuring posterior part of ventral contact margin in lateral view; it terminates at posteroventral margin where it becomes a blunt projection over posterior margin. Dorsal ridge less prominent, starting in upper part of anterior marginal ridge, running posteriorly, bordering flat dorsal area, and terminating at posterodorsal corner where it sends two branches downward. Middle ridge starts at anterior margin and terminates in anterocentral area, where prominent vertical ridge connects with it in T-shape. Open area between ridges finely reticulate and pitted. Hinge straight; arrangement typical of genus. Anterior tooth of right valve small, crenulate. Median element socketed. Posterior tooth represented by one small round projecting tooth at termination of higher ridges of selvage. Adductor muscle scar located slightly anterior to center. Details of muscle scar and character of marginal area similar to *C. miurensis*, but sinuation of anterior inner margin at mid-height. In dorsal view, carapace oblong owing to lateral extension of ventral ridges. In anterior view, sub-trapezoidal owing to flat ventral and dorsal areas.

Dimensions: Holotype (complete carapace) length 0.46 mm., height 0.26 mm., thickness 0.22 mm.; paratype (complete carapace) length 0.41 mm., height 0.22 mm., thickness 0.20 mm.; paratype (complete carapace) length 0.42 mm., height 0.22 mm., thickness 0.21 mm.

Occurrence: All type specimens were collected from Recent beach sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture.

Remarks: This box-shaped species is quite different from typical *Cytherura* in its outline, but is otherwise similar. *Cytherura undata* from the north European coast has close relationship to this species, but is different in outline and ornamentation pattern.

Cytherura subundata Hanai, n. sp.

Plate III, figures 3 a–d; text-figures 2a, b.

Description: Carapace thick, sub-trapezoidal in lateral outline, highest anterior to middle. Right valve much higher and larger than left. Anterior margin obliquely and narrowly rounded at extremity, with two or three short, angular, tooth-like projections. Dorsal margin nearly straight, gently arched anteriorly and posteriorly; ventral margin nearly straight, slightly obscured by ventral ridge in posterior part. Dorsal and ventral margins nearly parallel. Posterior margin obliquely truncated above and forming a sharply angulated caudal process about mid-height. Surface ornamented with ridges having rather sharp edges. Ventral ridge starts at

anterior margin, runs posteriorly, and terminates at posteroventral corner in a blunt projection. Ventral ridge sharp-edged especially in posterior half, and sinuous at middle where a prominent ridge branches off obliquely toward posterodorsal corner. Along anterior margin, ventral ridge becomes anterior marginal ridge running to anterior cardinal angle where it is sufficiently high to obscure contact margin. It continues to run along dorsal margin and terminates at posterior caudal process in right valve; in left valve it becomes obscure along the dorsal margin in lateral view. Eye spot round and distinct, giving rise to a ridge below, which changes direction at mid-height in L-shape and connects with anterior margin. Open areas ornamented by fine reticulation. Hinge arrangement typical of genus. Flange, which develops above actual hingement in the right valve, modified by a strong ridge parallel to it making a deep groove between. Details of hingement and marginal area similar to those of *C. quadrata* Hanai, Adductor muscle scar typical of genus. In dorsal view, sub-rhombic owing to lateral expansion of the ventral ridges. In anterior view, sub-trapezoidal with dorsal area of right valve projected. Ventral area flat and sub-rhombic in ventral view.

Dimensions: Holotype (a right valve) length 0.63 mm., height 0.35 mm.; paratype (a left valve) length 0.65 mm., height 0.36 mm.; paratype (a right valve) length 0.68 mm., height 0.39 mm.; paratype (a left valve) leugth 0.60 mm., height 0.33 mm.

Occurrence: The holotype and the two left valves of paratypes were obtained from the Sawane formation (Upper Pliocene) at the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture (Collected by T. Uchio). The same species also occurs in the Setana formation (Upper Pliocene) in the valley of Toshibetsu-gawa, about 800 meters W. of Omagari, Toshibetsu-mura, Setana-gun, Hokkaido (=Aasano, 1950, Loc. C-4). One paratype of the right valve is from the Setana formation.

Remarks: The group of *Cytherura* which is characterized by a thick shell and a grooved flange structure just above the hingement of right valve includes the forms most different from typical *Cytherura*. However, the hinge structure and the character of the marginal area are essentially closely related to each other.

Cytherura leptocytheroidea Hanai, n. sp.

Plate III, figures 2 a, b.

Description: Carapace thick oblong in lateral view. Anterior margin obliquely rounded; dorsal margin slightly arched, inclined posteriorly; ventral margin nearly straight. Posterior caudal process blunt and inconspicuous, located below mid-height and down-turned. Surface ornamented with undulated ridges having flat tops. Height of main ridges almost constant, width variable. Anterior marginal ridge starts at lower part of anterior margin, runs upward obliquely in the antero-dorsal area and almost reaches the dorsal margin, then runs the length of the dorsal margin, and terminates in upper half of posterior margin. Eye spot distinct, giving rise downward to an L-shaped ridge terminating at anterior marginal ridge. Ventral ridge starts at lower part of anterior margin, runs posteroventrally, obscuring ventral margin at its middle, turns upward making a rather smooth curve across posteroventral and posterior area of carapace and terminates near posterodorsal corner. Two irregular vertical ridges prominent in central area. Open areas irregularly finely reticulate. Character of hingement and flange structure in right valve, marginal area, and of adductor muscle scar similar to that of *Cytherura subundata* Hanai. In anterior view, oval with flat ventral surface, and more or less pro-

jecting dorsal marginal area in right valve.

Dimensions: Holotype (complete carapace) length 0.55 mm., height 0.32 mm., thickness 0.27 mm.; paratype (a right valve) length 0.55 mm., height 0.33 mm.

Occurrence: All type specimens were collected from the Setana formation (Upper Pliocene) in the valley of Toshibetsugawa, about 800 meters W. of Omagari, oIshibetsu-mura, Setana-gun, Hokkaido.

Remarks: This species belongs to the same group as *Cytherura subundata* HANAI, but in this species the ornamentation of the carapace is more complicated.

Gedus *Howeina* HANAI, n. gen.

Type species: *Howeina camptocytheroidea* HANAI, n. sp.

Diagnosis: Cytherurinae with arched *Cytherura* type hingement, but anterior tooth of right valve large and elongated. Ventral surface has slight wing-like ridges. Posterior caudal process indistinct. Inner margin makes modified S-shape along posterior margin. Eye spot indistinct.

Description: Carapace large for this subfamily, ovate in lateral view, right valve slightly overlapping left on dorsal margin, and left overlapping right on ventral margin. Ventral surface has slight wing-like ridges. Caudal process obscure. Nature of marginal area and radial pore canals similar to *Cytherura*, showing modified S-shaped inner margin along posterior margin, but development of inner lamella varies considerably within any one species. Hinge merodont, of arched *Cytherura* type with no crenulations. Hingement of right valve with characteristic large, elongate anterior terminal tooth and small, knob-like posterior terminal tooth at ends of blade-like extension of outer margin of inner lamella. Above hinge element, flange overhangs strongly but does not quite reach teeth, making wide furrow between the teeth and the flange. Hingement of left valve complementary to that of right and similar to that of *Cytherura*. Median bar and flange over bar almost same height in dorsal view, fused along middle portion. Terminal portion of bar thickened and truncated at ends Adductor muscle scar consists of four posterior vertical scars and one anterior scar located near center of carapace. Eye spot obscure.

Remarks: This genus has close resemblance to *Camptocythere* from the Jurassic of Germany in its hinge structure, but the character of the marginal area is quite different, especially in the nature of the radial pore canals. The closest genus to *Howeina* is *Cytherura*. Differences between the two are given in the diagnosis of the new species. The genus is named in honor of Dr. Henry, V. HOWE, Director, School of Geology, Louisiana State University.

Howeina camptocytheroidea HANAI, n. sp.

Plate III, figures 4 a–c; text-figures 5 a, b.

Description: Carapace rather thin and ovate in side view, highest at anterior cardinal angle. Anterior margin obliquely rounded, dorsal margin slightly arched. Ventral margin nearly straight. Posterior margin truncated obliquely in upper and lower portions, so as to form an angulation with a rather blunt and round tip which is strong in left valve, and, sometimes, upper half of posterior margin slightly concave outward. Surface pitted in posterodorsal to central area; pits arranged more or less parallel to posterodorsal margin. Irregular polygonal network of fine ridges developed in anterior and posterior areas. Slight wing-like expansion runs from

anteroventral area to posteroventral area where it turns upward making a round curve and continues a short distance. Just posterior to wing-like expansion, carapace is slightly depressed. Ventral area more or less flat and having several fine longitudinal ridges which run almost parallel to ventral contact margin. Marginal area, hinge structure, and the muscle-scar pattern same as for genus. Viewed from above, carapace appears to be slightly compressed anteriorly, thickest a little posterior to middle. In anterior view, carapace subovate with more or less flattened ventral surface, thickest just below mid-height.

Dimensions: Holotype (a right valve) length 0.62 mm., height 0.37 mm.; paratype (a left valve) length 0.64 mm., height 0.35 mm.; paratype (a left valve) length 0.63 mm., height 0.36 mm.; paratype (complete carapace) length 0.64 mm., height 0.39 mm., thickness 0.33 mm.

Occurrence: All type specimens were obtained from the Setana formation (Upper Pliocene) at Kaigarazawa, about 500 meters W. of Nishinosawa, Kuromatsunai-mura, Suttsu-gun, Hokkaido, where they are abundant.

Genus *Hemicytherura* Elofson, 1941

Cythere, Cytherura, Cytheropteron auct. (part.)
1941 *Cytheropteron* (*Hemicytherura*) Elofson, p. 304.
1952 *Cytherura* (*Hemicytherura*) Ruggieri, p. 85.
1952 *Hemicytherura* Hornibrook, (part.) p. 58.
1953 —— Ruggieri, Iconografia, pp. 48, 49.

Type species: Cythere cellulosa Norman, 1865.

Diagnosis: Cytherurinae having subrhomoboidal carapace with narrowly rounded and crenulate anterior margin. Caudal process conspicuous. Surface reticulate. Hinge merodont, of arched *Cytherura* type. Terminal teeth of right valve knob-like, one or two (rarely more than two) at termination of more or less poorly developed blade-like ridge of inner lamella. Marginal area well developed, nearly parallel to outer margin. Line of concrescence coincides with inner margin. Radial pore canals gathered into about three groups along anterior margin. Eye spot clear.

Description: Carapace small, subrhomboidal, and lenticular, with conspicuous caudal process. Anterior margin narrowly rounded and crenulate. Right valve larger than left, overlapping left along dorsal margin. However, at caudal process, left valve overlaps right. Surface usually reticulate. Marginal area wide, line of concrescence usually coincides with inner margin and runs roughly parallel to outer margin. Small triangular vestibule sometimes develops anteriorly. Radial pore canals few, having a tendency to be grouped. Normal pore canals also few, scattered. Hinge merodont, arched, of *Cytherura* type. Right valve with small terminal teeth, one or two (rarely more than two) at each end of blade-like ridge of inner lamella. Median groove between terminal teeth arched and strongly crenulate in its terminal parts. Hinge of left valve consists of arched median bar which is thickened and crenulate in its terminal protion, and complementary terminal sockets. Median bar projects over flange in dorsal view. Flange projects just above terminal sockets fitting furrow between terminal teeth and overhanging flange of right valve. Adductor muscle scar consists of four vertically arranged posterior scars and one anterior scar. Eye spot clear.

Hemicytherura kajiyamai HANAI, n. sp.

Plate II, figures 1 a–d.

1913 *Cytheropteron videns*, KAJIYAMA, pp. 4, 5, pl. 1, figs. 19–25.

Description: Carapace small, thick, subrhomboidal; in lateral outline highest at middle, having four crenulations on anterior margin; dorsal margin high and strongly arched; ventral margin nearly straight, obscured by ventral ridge in its posterior half. Caudal process moderately strong. Ventral ridge makes distinct angulation at posteroventral corner. Surface ornamented by widely open reticulation pattern; anterior two reticulations obliquely elongate, dorsal reticulations more or less fan-shaped, central reticulation round, ventral reticulations elongate along ventral margin. Ridges of reticulations smooth; areas surrounded by ridges ornamented with smaller reticulations, and having one or two small nodes located subcentrally. Along dorsal margin, one ridge runs from anterodorsal corner to caudal process. This ridge projects above dorsal contact margin in right valve. Hinge structure, character of marginal area and adductor muscle-scar pattern typical of genus. In dorsal view, carapace lenticular; in anterior view, ovate, truncated below where ventral ridge gives distinct angulation. Between ventral ridges of the valves, ventral area nearly flat.

Dimensions: Holotype (complete carapace) length 0.37 mm., height 0.22 mm., thickness 0.18 mm.; paratype (complete carapace) length 0.37 mm., height 0.22 mm., thickness 0.18 mm.

Occurrence: All types were collected from Recent beach sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture. This species also occurs in the Suganuma sandstone conglomerate bed of the Oidawara tuffaceous mudstone (Miocene) in the valley east of Suganuma, Hiyoshi-mura, Toki-gun, Gifu Prefecture. (Collected by T. OGOSE).

Remarks: *Hemicytherura videns* (G. W. MÜLLER) was originally described from the Gulf of Naples as *Cytheropteron videns*. In 1912, G. W. MÜLLER listed its name again in "Das Tierreich". In 1941, ELOFSON, in his study of the Skagerak Ostracoda, proposed the name *Hemicytherura* as a subgenus of *Cytheropteron*, designating *Cythere cellulosa* NORMAN as the type species. He included *Cytheropteron videns* in the subgenus *Hemicytherura*. ROME (1942) reported this species from the environs of Monaco as *Cytheropteron videns*. KLIE (1942) described this species from the Adriatic Sea as *Cytheropteron* (*Hemicytherura*) *videns*. Thus the distribution of *Hemicytherura videns* is limited to the Atlantic and Mediterranean regions. No *Hemicytherura videns* have yet been reported from the Pacific region. KAJIYAMA's *Cytheropteron videns* is quite different from the European species in its ornamentation and outline, and is here described as a new species. *Hemicytherura fereplana* HORNIBROOK has close resemblance to *Hemicytherura kajiyamai* HANAI, n. sp., but has a different reticulation pattern. This genus is named in honor of Mr. E. KAJIYAMA.

Hemicytherura cuneata HANAI, n. sp.

Plate II, figures 2 a, b; text-figures 1 a, b.

Description: Carapace small and thick, sub-rhomboidal in lateral outline, highest a little posterior to anterior cardinal angle. Anterior margin obliquely rounded with four crenulations in narrowly rounded lower half. Ventral and dorsal margin nearly parallel; dorsal margin slightly inclined toward posterior. Caudal process

distinct in right valve, rather obtuse in left valve. Posterior caudal area compressed. Eye spot distinct. Dorsal ridges of both valves surround dorsal flattened area. Straight ventral ridge starts at lower part of anterior margin, runs posteriorly bordering ventral flattened area, turns upward at posteroventral corner without distinct angulation and runs across posterocentral area. Surface ornamented with irregular reticulations, of which the central one is large and more or less elliptical in shape; lower boundary of central reticulation makes a distinct ridge which continues straight to anterior margin. Other reticulations essentially formed by radial ridges connecting central reticulation and marginal ridges. Open areas between reticulations ornamented with finer reticulations. Dorsal flattened area ornamented with very fine pits aligned parallel to hinge line. Hinge structure, character of marginal area, and adductor muscle-scar pattern typical of genus. In dorsal view, carapace lenticular. In anterior view, carapace more or less trapezoidal with dorsal ridge projecting in right valve.

Dimensions: Holotype (complete carapace) length 0.37 mm., height 0.23 mm., thickness 0.21 mm.; paratype (complete carapace) length 0.39 mm., height 0.24 mm., thickness 0.21 mm.

Occurrence: All type specimens were obtained from Recent beach sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture.

Remarks: This species shows very close relationship to *Hemicytherura pentagona* Hornibrook. The minor difference in surface ornamentation suggests that this species may be merely a geographic variant of the New Zealand species. Named for the wedge-shape of this species.

Hemicytherura tricarinata Hanai, n. sp.

Plate II, figures 3 a, b.

Description: Carapace small and thick, subrhomboidal in lateral outline, highest at middle. Anterior margin obliquely rounded. Dorsal margin gently arched and gradually transitional to posterior margin. Ventral margin straight. Caudal process inconspicuous and rather obtuse. Posterior caudal area compressed. Surface ornamented with three prominent ridges aligned longitudinally. Dorsal ridge starts at middle of anterior margin, runs along dorsal margin, and connects with ventral margin in posterior area. Ventral ridge starts at anterior margin, runs posteriorly nearly parallel to ventral margin, obscuring it in posterior half, and turns upward at posteroventral corner connecting with dorsal ridge. Median ridge runs nearly straight from anterior margin to junction of ventral and dorsal ridges. The two open areas are intersected by three vertical ridges forming a coarsely reticulate pattern. Open areas between reticulation have finely granular ornamentation. Some ridges have one or two nodes. Hinge structure, character of marginal area and adductor muscle-scar pattern typical of genus. In dorsal view, carapace lenticular. In anterior view, carapace sub-trapezoidal, with dorsal ridge of right valve projecting above contact margin. Ventral area between more or less alar ridges of both valve nearly flat.

Dimensions: Holotype (complete carapace) length 0.39 mm., height 0.22 mm., thickness 0.18 mm., paratype (complete carapace) length 0.37 mm., height 0.21 mm., thickness 0.18 mm.

Occurrence: All type specimens were obtained from Recent beach sand from the shore about 1 km. NE of Akase railroad station, near Hiraiwa, Auda-mura, Uto-gun, Kumamoto Prefecture.

Remarks: This species has close resemblance to *Hemicytherura quadrazea* HORNIBROOK, but differs in detail of ornamention, especially in the posterior part of the median ridge.

Subfamily Cytheropterinae HANAI, n. subfam.

1894 Cytherurinae G. W. MÜLLER, (part.) p. 286
1926 Loxoconchinae G. O. SARS, (part.) p. 217.
1938 Cytherurinae KLIE, (part.) p. 187.
1941 —— ELOFSON, (part.) pp. 304, 305.
1955 —— SWAIN, (part.) p. 626.

Type Genus: *Cytheropteron* G. O. SARS, 1865 (1866).

Diagnosis: Carapace small with strong wing-like lateral expansions and caudal process. Surface weekly to strongly sculptured. Valves conspicuously unequal. Hinge merodont, arched and of *Cytheropteron* type. Area of concrescence moderately broad. Inner margin nearly parallel to outer margin. Vestibule present. Radial pore canals few and simple. Normal pore canals few and scattered. Adductor muscle-scar pattern consists of four posterior vertical scars with one scar in front. Eye spot usually indistinct.

Remarks: As it was pointed out by ELOFSON (1941), genus *Cytheropteron* is closely related to genus *Cytherura*, but it differs definitely from genus *Loxoconcha* in its appendage structures. The typical merodont hingement of Cytheropterinae is related rather closely to that of subfamily Cytherinae of strict sense. DUBOWSKY (1939) and RUGGIERI (1952) described some genera which have characters intermediate between genus *Cytheropteron* and genus *Paracytheridea*. It is, therefore, most likely to be concluded that the Ostracoda classified into the *Paracytheridea* subgroup in this paper are also related very closely to subfamily Cytheropterinae. However, the definite relationship between the two is still of uncertain status. No opportunity has been afforded for the writer to study the type species of *Paracytheridea* and its allied genera.

Subfamily Cytheropterinae includes at least the following genera or subgenera:
Cytheropteron G. O. SARS, 1865 (1866).
Aversovalva HORNIBROOK, 1952.
Kangarina CORYELL and FIELDS, 1937.
Kobayashiina HANAI, n. gen.

Genus *Cytheropteron* G. O. SARS, 1865 (1866)

Cythere auct. (part.)
1865 (1866) *Cytheropteron* G. O. SARS, pp. 79, 80.
1868 —— BRADY, Int. Obs., p. 124.
1868 —— BRADY, Mon., p. 447.
1874 —— BRADY, CROSSKEY and ROBERTSON, pp. 201, 202.
1878 —— BRADY, Antwerp., p. 402.
1880 —— BRADY, p. 135.
1889 —— BRADY and NORMAN, p. 207, (Designition of type species).
1894 —— LIENENKLAUS, p. 243.
1894 —— G. W. MÜLLER, p. 300.
1900 —— LIENENKLAUS, p. 541.
1900 —— NAMIAS, p. 110.
1905 —— LIENENKLAUS, p. 54.
1909 —— G. W. MÜLLER, p. 107.

1912 —— G. W. MÜLLER, p. 273.
1913 —— KAJIYAMA, p. 4.
1926 —— G. O. SARS, p. 223.
1928 —— NEVIANI, pp. 35, 36.
1929 —— ALEXANDER, p. 102.
1933 —— (*Cytheropteron*) ALEXANDER, pp. 187–190.
1934 —— (——) ALEXANDER, pp. 229, 230.
1936 —— VAN VEEN, p. 70.
1938 —— KLIE, Tierwelt, pp. 200, 201.
1939 —— SUTTON and WILLIAMS, p. 573.
1939 —— (*Cytheropteron*) MARTIN, pp. 176, 177.
1941 —— BONNEMA, p. 26.
1941 —— (*Cytheropteron*) ELOFSON, pp. 313–316.
1941 —— TRESSLER, p. 101.
1946 —— (*Cytheropteron*) VAN DEN BOLD, p. 33.
1946 —— STEPHENSON, p. 318.
1948 —— (*Cytheropteron*) KINGMA, p. 24.
1952 —— (——) HORNIBROOK, p. 52.
1953 —— (——) BOWEN, p. 280.

Type species: *Cythere latissima* NORMAN, 1865.

Diagnosis: Cytheropteroninae having wing-like lateral projections and upturned caudal process. Right valve larger than left. Hinge merodont, of arched *Cytheropteron* type; right valve has crenulate terminal teeth at each end of hingement and a crenutate groove between, which is obscure in its middle part. Hinge of left valve consists of complementary terminal sockets and crenulate bar between. Marginal area moderately developed with anterior vestibule. Radial pore canals rather simple. Eye spot obscure.

Description: Carapace subrhomboidal to ovate in lateral outline, with upturned and compressed caudal process. Wing-like lateral expansions prominent. Valves unequal, usually right valve slightly larger than left, especially along dorsal margin, but left overlaps right in posterior caudal area. Hinge merodont, of arched *Cytheropteron* type. Right valve has crenulate terminal teeth at each end of hinge margin. Posterior teeth usually more elongated than anterior and often somewhat upturned. Well-developed arched flange hangs over actual hinge element. Furrow between teeth and flange of right valve distinct, receiving flange above terminal sockets of left valve. Groove between terminal teeth of right valve strongly crenulate in terminal parts. Corresponding bar of left valve arched and thin in middle part and thickened and strongly crenulate in terminal parts, especially in posterior terminal portion. This bar projects over the edge of the carapace in dorsal view. Marginal area moderately developed, and inner margin nearly parallel to out margin. Vestibule usually well developed anteriorly. Radial pore canals few, usually simple, sometimes bifurcated. Adductor muscle-scar pattern located in central area but a little below mid-height, and consisting of four vertically arranged posterior scars and one or sometimes two anterior scars.

Cytheropteron sawanense HANAI, n. sp.

Plate IV, figures 2 a–c; text-figures 8 a, b.

Description: Carapace thick, subrhomboidal in lateral outline, highest at middle. Anterior margin obliquely rounded, dorsal margin high and strongly arched, ventral outline obscured by a keeled ala, which is narrowly rounded in its posterior

part. Keel continues to anterior margin where it bifurcates. Caudal pronounced, upturned. Strong ridge starts at anterior margin, runs parallel to dorsal margin into posterior caudal area: it is especially strong at anterodorsal and posterodorsal corners. Surface ornamented with coarse punctations aligned vertically. At its middle, ventral ala has a sulcus-like depression on its upper surface. Hinge structure, character of marginal area, and adductor muscle-scars typical of genus. In dorsal view, carapace teardrop shaped with triangular caudal process. In anterior view, carapace triangular.

Dimensions: Holotype (a right valve) length 0.62 mm., height 0.39 mm., thickness 0.25 mm., paratype (a right valve) length 0.62 mm., height 0.38 mm., thickness 0.25 mm., paratype (a left valve) length 0.60 mm., height 0.35 mm., thickness 0.21 mm., paratype (a left valve) length 0.59 mm., height 0.35 mm., thickness 0.21 mm.

Occurrence: All type specimens were collected from the Sawane formation (Upper Pliocene) from the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata prefecture. (Collected by T. UCHIO.)

Remarks: This species is similar to *Cytheropteron fornix* HORNIBROOK in outline and shape of the keeled ala, but is different in other ornamentations such as punctation pattern, strength of the dorsal ridge, and presence of a sulcus-like depression.

Cytheropteron uchioi HANAI, n. sp.

Plate IV, figures 4 a, b; text-figures 9 a, b.

Description: Carapace thick, subrhomobidal in lateral outline, highest at middle. Anterior margin obliquely rounded, dorsal margin arched and moderately high. Anterodorsal corner of left valve sinuous. Ventral margin obscured by strong, blunt, and more or less rounded ala, extending from anterior margin and having a pit at its middle. Caudal process rather broad, truncated at its tip. Surface nearly smooth with some punctations in central part. At least three very fine, vertical ridges visible in central area. Along edge of ala are two or three very fine ridges running paralel to edge. Hingement, character of the marginal area and the adductor muscle-scar pattern typical of genus. Radial pore canals do not reach anterior margin. In dorsal view, carapace spade-shaped with a rather small triangular caudal process. In anterior view the carapace is triangular.

Dimensions: Holotype (a right valve) length 0.63 mm., height 0.43 mm., thickness 0.27 mm.; paratype (a right valve) length 0.61 mm., height 0.46 mm., thickness 0.25 mm.; paratype (a left valve) length 0.60 mm., height 0.41 mm., thickness 0.22 mm.; paratype (a left valve) length 0.67 mm., height 0.43 mm., thickness 0.26 mm.

Occurrence: All type specimens were collected from the *Cucullaea* zone of the Heki Formation (Pliocene) at a point west of Idenoue, Kawaminami-mura, Koyu-gun, Miyazaki Prefecture.

Remarks: The lateral and dorsal outlines of this species have some resemblance to *Cytheropteron* "sp. A" of KINGMA.

Cytheropteron rarum HANAI, n. sp.

Plate IV, figure 3.

Description: Carapace somewhat thin, subrhomobidal in lateral outline. Anterior margin obliquely rounded, dorsal and ventral margins sub-parallel. A strong, sharp-edged, more or less rounded ala, starts in anteroventral area, runs posteriorly

making a gently convex curve laterally and turns up to mid-height without making any distinct corner in posteroventral area. Ventral margin obscured by ala in posterior half. Posterior margin obliquely rounded upward owing to inconspicuous, very blunt, upturned caudal process. Surface sculptured by vertical and irregularly arranged ridges in posterior half; ridges connected by longitudinal ridges so as to make vertically elongate reticulations. Anterior half of carapace has smooth surface. Ala has a prominent depression at middle of upper surface. Hinge structure slightly longer and more fragile than typical *Cytheropteron*. Adductor muscle scars and marginal area typical of genus. In anterior view, carapace subtriangular with somewhat inflated lateral outline. Viewed dorsally, carapace appears spade-shaped. Dorsal flat surface ornamented with longitudinal ridges and a series of small pits.

Dimensions: Holotype (a left valve) length 0.64 mm., height 0.38 mm., thickness 0.28 mm.

Occurrence: The type specimen was obtained from the Sawane formation (Upper Pliocene) from the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture (Collected by T. Uchio).

Remarks: The vertically elongate pattern of reticulation on the posterior part of the carapace is characteristic of this species. The somewhat fragile carapace indicates slight deviation of this species from typical *Cytheropteron*.

Cytheropteron miurense Hanai, n. sp.

Plate IV, figures 1 a, b; text-figures 7 a, b.

Description: Carapace small, thick, sub-rhomboidal in lateral outline, highest at middle. Anterior margin obliquely and strongly rounded, dorsal margin strongly arched in anterior half and strongly concave in posterior half. Posterior margin angular, making nearly a right angle with dorsal margin. Caudal process moderately strong. Ventral margin obscured by ala; posterior cardinal angle distinct. Ala very blunt. Blunt ridges runs along dorsal margin. Surface ornamented with numerous punctations arranged in more or less vertical rows. Punctations coarser in posterior half of carapace. In posterocentral area, punctations connected vertically, forming vertical rows of punctate grooves. Marginal area moderately broad, broadest at anterior and posterior ends. Radial pore canals not numerous, and bifurcated. Vestibule poorly developed along anterior margin, broadest at anteroventral margin. Hinge line curves in S-shape in interior view. Hingement of right valve consists of anterior and posterior teeth and intermediate crenulate groove. Intermediate element subdivided into three sections: short anterior groove with three large crenulations, median arched non-grooved area, and concave posterior groove with six large crenulations, of which anterior three are strongly serrated and shallow, and posterior three are connected and deep. Hingement of left valve complementary to right, consisting of anterior and posterior sockets and intermediate crenulate ridges. Intermediate element subdivided into three sections: anterior crenulate ridge, arched high and sharp intermediate ridge, and posterior crenulate ridge which consists of anterior three strongly serrated crenulations and posterior more or less fused crenulations. High arched median ridge fits just under strongly ached and projecting flange of right valve. Adductor muscle scar, located anteroventral to center, and consists of four vertically arranged elongate scars with an obliquely elongated scar in front. In dorsal view, carapace triangular with caudal process projecting. In anterior view, carapace triangular truncated above by small flat dorsal area.

Dimensions: Holotype (complete carapace) length 0.49 mm., height 0.32 mm., thickness 0.34 mm.

Occurrence: The holotype occurs in Recent shell sand from the shore behind an Imperial villa, Hayama-machi, Kanagawa Prefecture, where this species is rare.

Remarks: This species is closely related to *Cytheropteron dividentum* HORNIBROOK. However, the Japanese species does not possess a projection in the lower half of the posterior margin and the punctations are much more numerous than in *C. dividentum*.

Genus *Kobayashiina* HANAI, n. gen.

Type species: *Kobayashiina hyalinosa* HANAI, n. sp.

Diagnosis: Carapace fragile and nearly transparent, shaped like *Cytheropteron* with sharp, pointed ala. Caudal process turned downward. Hingement of right valve consists of anterior, large, knob-like split tooth, median finely crenulate furrow, and posterior tooth which consists of a row of small, elongate, knob-like teeth. Anterior tooth has a step-like projection just below it. Median furrow has a shallow depression at anterior termination, and has no distinct interior raised margin except at middle where anterior finely crenulate and arched part turns into straight, more or less coarsely crenulate part. Inside of shell swells up so as to form elongate tooth-like projection at middle of interior margin of furrow. Hingement of left valve complementary, except anterior socket which has a prominent antislip-tooth-like projection on its inner margin. Character of marginal area and adductor muscle-scar pattern similar to that of *Cytheropteron*.

Description: Carapace sub-triangular due to development of down-turned caudal process. On anterior end, a prominent flaring outer margin turns outward. Surface smooth and glossy. Adductor muscle-scar pattern visible from outside, consisting of a vertical row of four scars with one scar in front and at least two scars above anterior scar. Marginal area moderately developed, with anterior vestibule. Radial pore canals few, about ten in anterior margin and three in posterior margin, not extending the width of the duplicature on anterior margin. Normal pore canals not numerous. Hingement of genus as defined in diagnosis. Right valve larger than left, overlapping it distinctly in posterior part of dorsal margin.

Remarks: This genus is closely related to the genus *Cytheropteron*, but it is clearly different in hinge structure, especially in anterior tooth-and-socket structure. The inner swelling of the middle part of the median furrow in right valve and corresponding depressions of the median bar in the left valve are also characteristic of this genus. It is named after Dr. Teiichi KOBAYASHI, Professor of Geology, University of Tokyo, under whose guidance the writer commenced the study of Ostracoda.

Kobayashiina hyalinosa HANAI, n. sp.

Plate IV, figures 5 a, b; texts-figures 6 a, b.

Description: Carapace thin, fragile and sub-transparent, sub-triangular in lateral outline. Anterior margin obliquely rounded, dorsal margin moderately arched and inclined posteriorly, ventral margin moderately convex, inclined upward slightly. Point of ala obscures ventral margin for short distance in posterior part. Posterior caudal process large and blunt, directed slightly downward and truncated at posterior end. Ala prominent; outer border of ala gently convex and keeled; ventrola-

teral angle of ala distinct and having a sharp spine pointing posterolaterally. Upper surface of ala has a small but deep cut parallel to margin. Surface smooth and glossy. Hinge structure, nature of the marginal area, and adductor muscle-scar pattern same as for genus. In anterior view, carapace sub-triangular. Viewed ventrally, carapace appears in arrow-head shape with more or less convex anterolateral margin and concave posterolateral margin. Ala has a pit on ventral side.

Dimensions: Holotype (a right valve) length 0.67 mm., height 0.39 mm., thickness 0.21 mm.; paratype (a right valve) length 0.65 mm., height 0.39 mm., thickness 0.19 mm.; paratype (left valve) length 0.70 mm., height 0.42 mm., thickness 0.21 mm.; paratype (a left valve) length 0.66 mm., height 0.39 mm., thickness 0.21 mm.

Occurrence: All type specimens were collected from the Sawane formation (Upper Pliocene) from the cliff at Mano Bay, Sawane-machi, Sado-gun, Niigata Prefecture, where they are common. (Collected by T. Uchio)

Remarks: The specific trivial name is derived from Greek, *hyalinos*, meaning glassy.

Conclusions

The following three groups which have subfamily rank are recognizable in the so-called cytherurine Ostracoda: 1) Cytherurinae, 2) Cytheropterinae, and 3) Eocytheropteron group. The Cytherurinae subfamily is characterized by a) the *Cytherura* type hingement, b) broad marginal area with irregular inner margin, c) no vestibule, or very poorly developed one, d) long, curved and grouped radial pore canals, and e) usually rather distinct eye spot. The Cytheropterinae subfamily is characterized by a) the *Cytheropteron* type hingement, b) moderately developed marginal area with inner margin running nearly parallel to outer margin, c) moderately developed vestibule, d) few and rather simple radial pore canals, and e) usually indistinct eye spot. In some genera of Cytheropterinae (e. g. *Kobayashiina*), the typical three-folded merodont hingement is modified into four-folded hingement in which the median element is differentiated into anteromedian finely crenulated and posteromedian coarsely crenulated elements. No representatives of the *Eocytheropteron* group have so far been found from Japan and vicinity.

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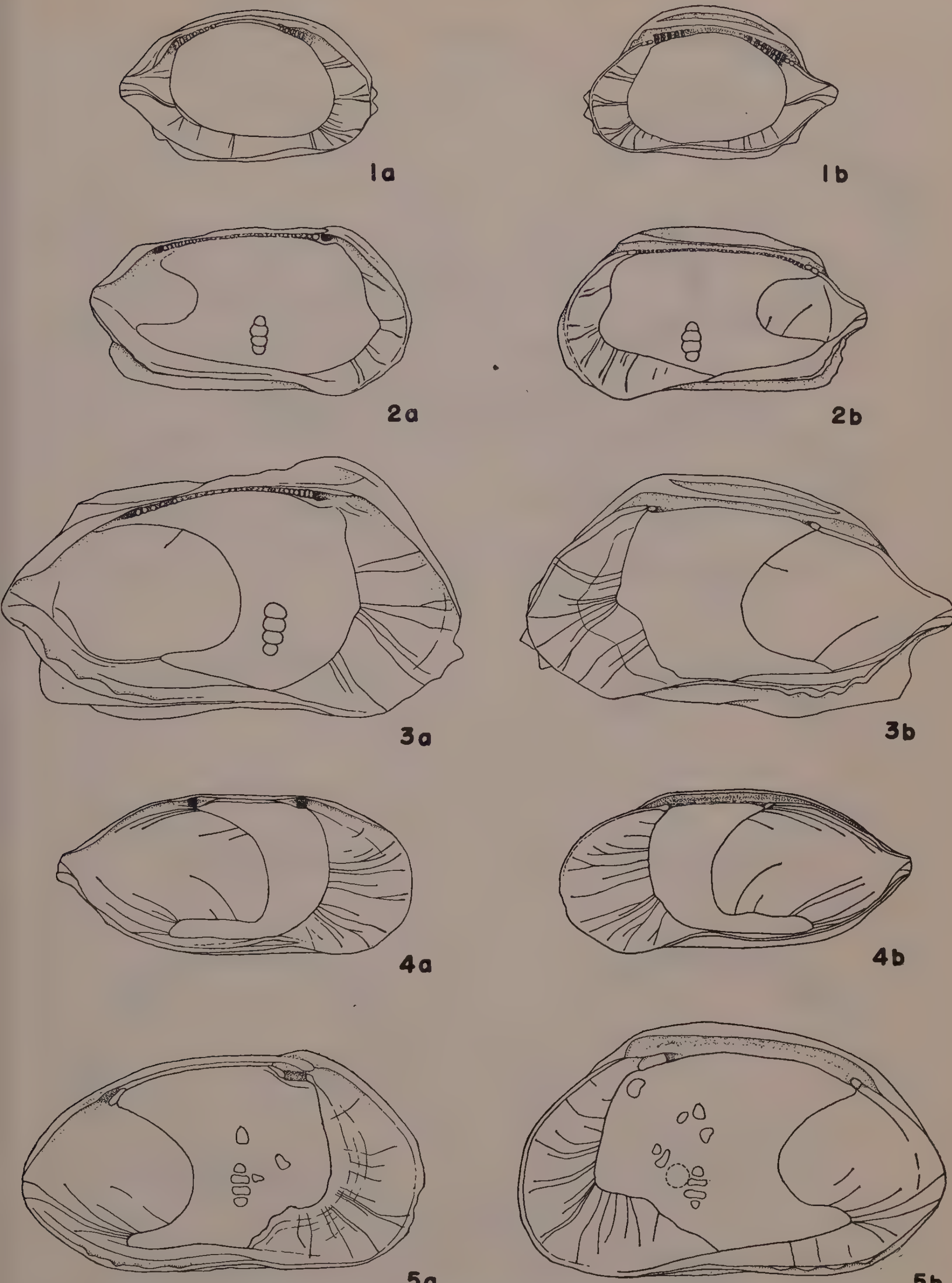

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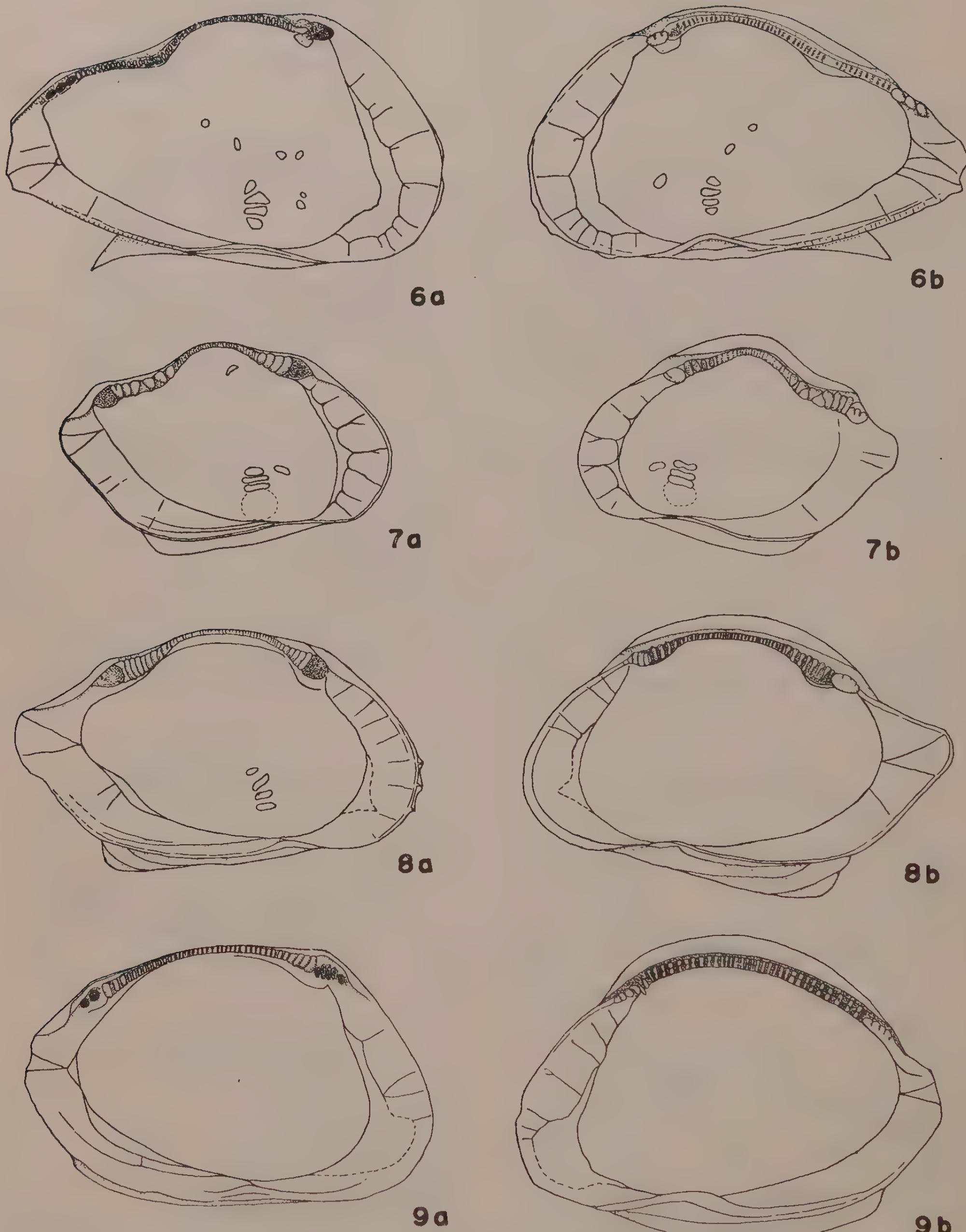

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III. Subfamilies Cytherurinae G. W. Müller (emend. G. O. Sars 1925) and Cytheropterinae n. subfam.

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1a
1d
5a
1b
1c
5b
2a
2b
5c
3a
3b
5d
4a
4b
6a
4c
4d
6b

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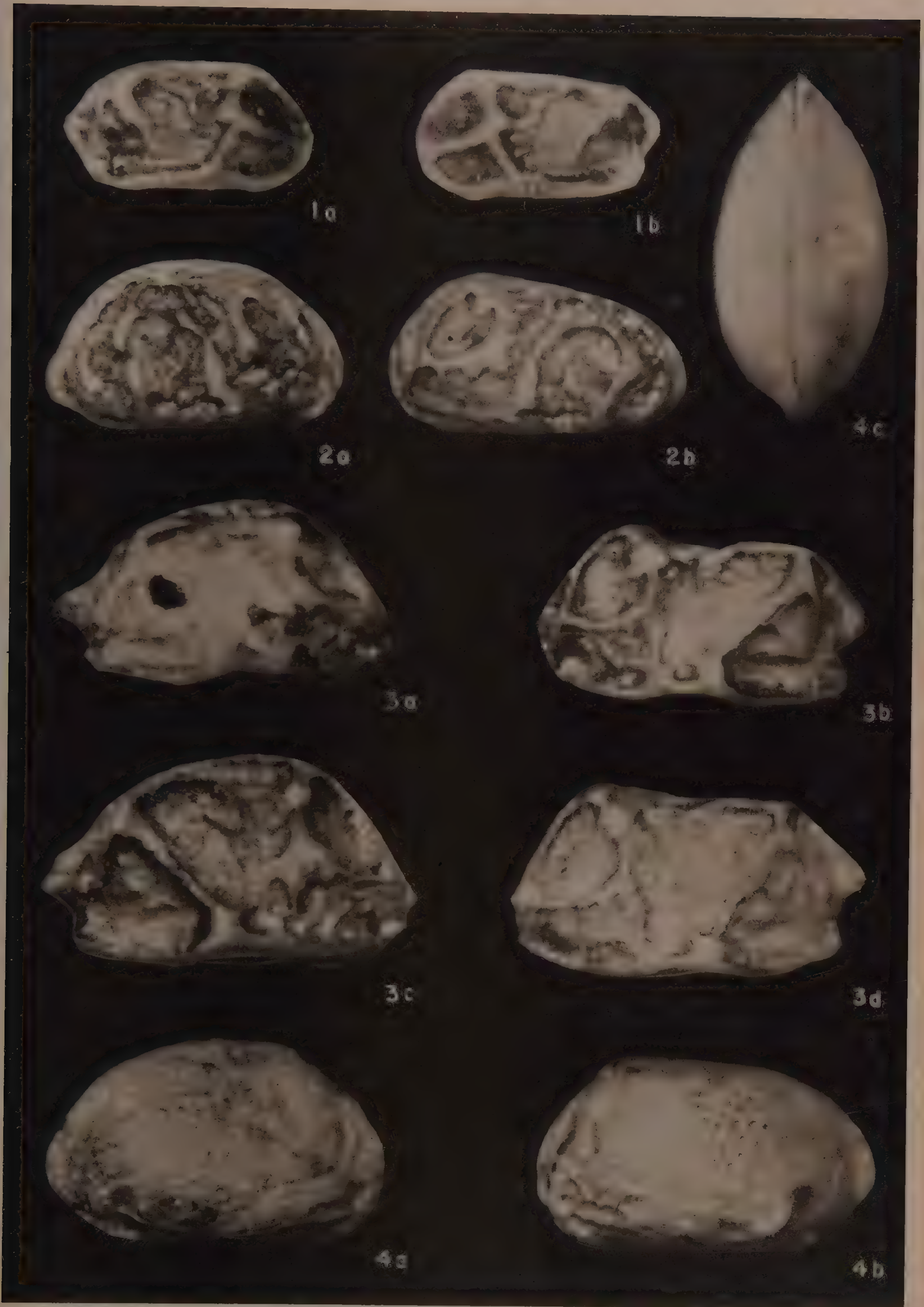
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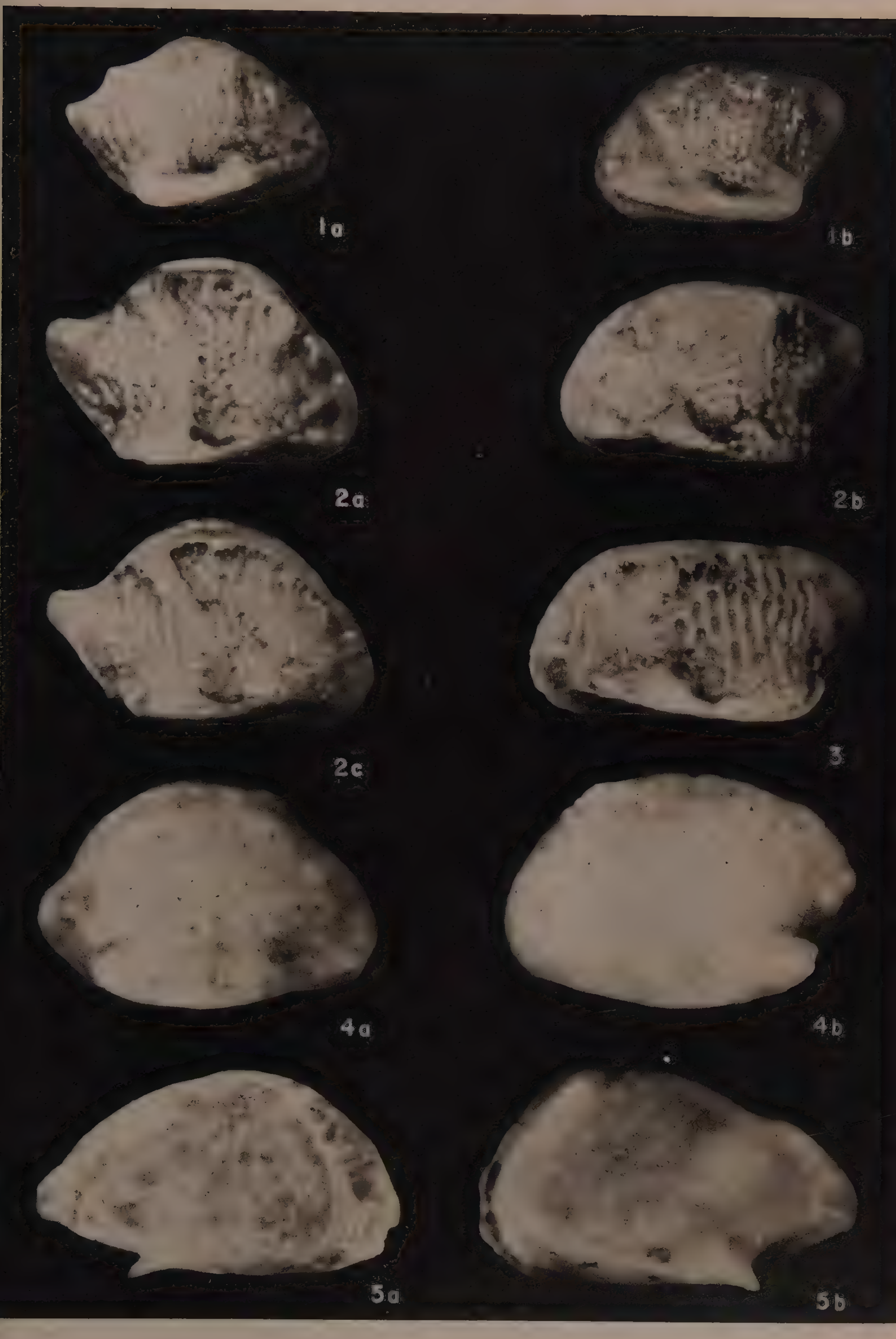
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2b
2c
3
4a
4b
5a
5b

PARTICLE SIZE DISTRIBUTION OF THF OBITSU DELTA

The Occurrence of the Steep Marginal Slope of a Small Scale Delta

By

Noriyuki NASU and Yoshiaki SATO*

Abstract

The main portion of the Obitsu Delta, which extends into Tokyo Bay, consists of well sorted medium to fine sands, while the bottom-set bed consists of muddy fractions, as can be seen in the results of the particle size distribution of the sediments. The fore-set bed between the top-set and the bottom-set beds forms a steep, narrow marginal slope which can be considered as a transition zone between the sandy area and that of mud.

It is well known that the settling velocity for a sand size fraction is distinctly faster than that for mud fraction; since, sand is quickly settled to the bottom when the water loses its transporting power, while the mud fractions stay in suspension for a longer period of time. Therefore, sand size fractions might well be accumulated at the river mouth, while the mud fractions might be carried out toward offshore area.

Therefore, the delta formation may well be interpreted as the significance of the separation of sediments into sand and mud fractions during the common processes of transportation.

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Introduction

Among the various findings in geology observed by the senior author, three sequences have aroused the attension from the hydrodynamical viewpoints. These are: well sorted sands occurred along beaches and sand dunes; sand and silt al-

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* Present address of the junior author is the Geological Survey of Japan, Tokyo.

ternations showing distinct boundaries between each layer; and the steep marginal slope of a small scale delta (Nasu, 1955).

It is well known principles in hydrodynamics that the settling velocity of sand or gravel is distinctly faster than that of silt-clay, because the resistant force acting upon a particle caused by water is only due to the surface friction, namely to the viscosity in silt-clay range; while that for gravel is caused mostly by the form-drag, and that for sand indicates the intermediate stage between the above two.

Therefore, sand and gravel settle to the bottom quickly soon after the transporting power of water current is weakened, while silt-clay is in suspension for a long period; if there is any horizontal advection or horizontal water mass exchange, it is transported for a long distance.

Also, the threshold mean flow velocity for sediments is minimal in fractional range of medium to fine sands. The mechanism causing such phenomenon will be explained later in this paper. Consequently, sand is initiated to the motion by the weakest current under which gravel or silt-clay is still in the resting position.

There widely exists such kind of current flows in nature, which accelerate the separation of sand from gravel or silt-clay, and sand tends to assemblage in the areas of limited extent forming massive body, and is well sorted. Therefore, transition range bordering the area of sand deposition and that of silt-clay or gravel is quite often narrow and sharp.

When it appears in the vertical sequence of sedimentary deposition, sand and mud layers accumulate alternately showing the distinct boundary between each layer. This process has been already discussed and interpreted by the senior author (Nasu, 1956 b).

Also, when this separation of sand mass from the rest of sediments occurs along the beach where waves are strong enough to churn up finer silt-clay fractions, sand beach is formed, because muddy fractions are transported and diffused toward offshore area by the horizontal diffusing action of water.

This process has also been reported in the preceding paper by illustrating the field data along the Gulf of Sagami in Japan (Nasu, 1956 a). In addition, the process forming dune sand is discussed in the same paper by interpreting the same sort of sorting action in air as well as in water.

Finally, it is discussed in this paper that sand mass constructs the main body of a delta showing the well sorted sand in its top-set bed as well as the upper half of the fore-set bed showing the steep marginal slope, when the separation occurs in comparatively calm water; where the wave action is not strong enough to diverge sand mass from the river mouth toward the outside area.

Since the particle size distribution of the Obitsu Delta in Tokyo Bay has been throughly investigated by the junior author (Sato, 1951), the result is illustrated here for the interpretation of the above mentioned sequence.

Generally speaking, a small scale delta may show mote typical profile of delta because of its steeper slope of the fore-set bed than that of a larger scale delta which may be often of a more complex type and consits of small scale deltas at each mouth of the tributaries.

It has been thought that delta formations may be due to the following causes: (1) the carrying power of the current is lost soon after it enters into the sea, thus the suspended sediment as well as the creeping sediment is settled in the vicinity of the river mouth; (2) in addition to this, the flocculation effect of clay and colloidal sediment accelerates the settling of the sediments because of changing physico-chemical conditions from the river into the sea.

Although the above statements are widely accepted, it should be especially emphasized here that the occurrence of a steep marginal slope on small scale deltas is the result of the separation of sands from muds during the common processes of transportation and deposition.

Acknowledgments

This study was initiated at the Geological Institute, University of Tokyo, and completed at the Scripps Institution of Oceanography, University of California.

The writers are sincerely indebted to Professors Takao Sakamoto and the late Yanosuke Otuka in the Geological Institute, University of Tokyo, and to Professors Francis P. Shepard and Douglas L. Inman of the Scripps Institution of Oceanography, University of California, for their guidance and assistance.

Also, the writers are especially indebted to Mr. Isamu Murai of the Earthquake Research Institute, University of Tokyo for his assistance and suggestions in the field survey as well as in the laboratory.

Although the results of the organisms study of this area are not described in this paper and will be mentioned in another paper, appreciation is also expressed to Dr. Isao Taki of the National Science Museum of Japan, Tokyo, and to Dr. Takayasu Uchio of the University of Tokyo for their identification of the organisms.

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Methods

The field survey and the sampling of sediments of the Obitsu Delta were undertaken in five days, July 26 to 30, 1950, along five profiles radiating into Tokyo Bay from the arcuate coast of the delta as shown in Figure 3. Seventy-five bottom samples were collected from 74 locations, and designated as Series B samples.

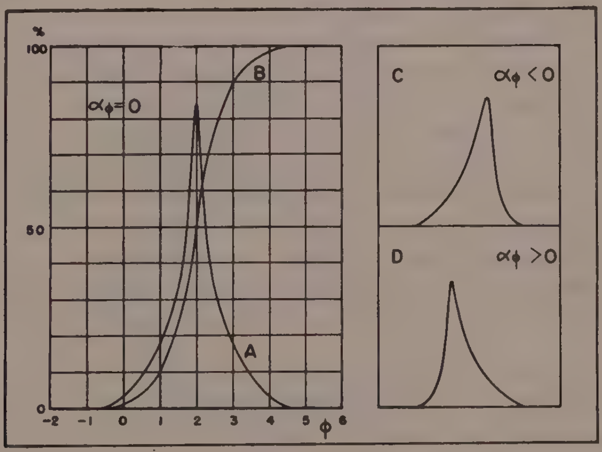

Fig. 1. (after Nasu, 1956a, P. 70)
Frequency Distribution Curves

A. Normal frequency distribution curve
B. Cumulative frequency curve of the above normal frequency distribution curve.
C. Skewed (negative) frequency distribution curve.
D. Skewed (positive) frequency distribution curve.

These samples were obtained in glass bottles directly from the tidal flat during the period of low tides, while those from shallow water bottoms were obtained by skin diving. The deeper bottom samples were collected from a boat by a Marukawa type snapper sampler (Cent. Meteo. Observ., Japan, 1956). The recorded depths all correspond to the standard reference level (Indian Spring Low Water, or approximately lowest low water) for the area studied.

A part of each sample was analyzed mechanically to obtain a curve showing the weight distribution as a function of the logarithm of particle size as shown in Figure 1. Sieving techniques and pipette methods were applied to sand and mud fractions respectively.

For convenience, the diameter of a particle, d, in millimeters, is replaced here by ϕ as expressed in equation (1).

(1) $d=1/2^{\phi}$ or $\log_{10}d=-\phi\ \log_{10}2$

When ϕ_{16}, ϕ_{50}, and ϕ_{84} are defined as the ϕ values for which the cumulative percent of sediment by weight is coarser than 16%, 50%, and 84% respectively, the phi median diameter Md_{ϕ}, the phi deviation measure (a measure of standard deviation or sorting) σ_{ϕ}, and the phi skewness measure α_{ϕ} are obtained from the following relations (after Inman, 1952).

(2) $Md_{\phi}=\phi_{50}$

(3) $M_{\phi}=\frac{1}{2}(\phi_{16}+\phi_{84})$

(4) $\sigma_{\phi}=\frac{1}{2}(\phi_{84}-\phi_{16})$

(5) $\alpha_{\phi}=(M_{\phi}-Md_{\phi})/\sigma_{\phi}$

The values obtained from equations (2) through (5) present graphical approximations of the true statistical values of median value Md, standard deviation σ, and skewness α_3 of the frequency distribution curve.

The reason adopting the Inman's phi measure system is that these measures represent the closer approximation to the true statistical values than those obtained from the quartile method and else.

The phi median diameter, Md_{ϕ}, will be used in this study as the measure of central tendency. The phi deviation measure, σ_{ϕ}, shows the magnitude of the horizontal scattering of the frequency curve. The smaller the σ_{ϕ}, the better the sorting. The skewness measure, α_{ϕ}, shows the degree of asymmetry of the size distribution: the larger the absolute value of α_{ϕ}, the stronger the degree of asymmetry. If the frequency curve is skewed as shown in Figure 1 C, 1 D, the value of α_{ϕ} will be negative or positive. If the curve has perfect symmetry then α_{ϕ} equals to zero.

These three measures are used in this paper to illustrate the size distribution of sediments, which are tabulated in Table I in the appendix.

The size classification of sediments used in this study is the following and is an adaptation of systems proposed by Wentworth (1922, p. 384), and Krumbein (1939, p. 566).

Class Range in mm. (Median diameter ranging from	Class Range in Phi Units (Median diameter ranging from)	Terminology	
$d>2$	$\phi<-1$	Gravel	
2 to 1	-1 to 0	Very Coarse	Sand
1 to 1/2	0 to 1	Coarse	Sand
1/2 to 1/4	1 to 2	Medium	Sand
1/4 to 1/8	2 to 3	Fine	Sand
1/8 to 1/16	3 to 4	Very Fine	Sand
1/16 to 1/256	4 to 8	Silt	Mud
$1/256>d$	$8<\phi$	Clay	Mud

Only a brief summary of method for the particle size distribution analyses is given here, since a detailed description is available in a previous paper (Nasu, 1956 a, pp. 68–73).

General Statement

Tokyo Bay is an ellipsoidal bay with the long axis trending NNE-SSW, and empties into the Pacific Ocean through Uraga Channel. The bay is quite shallow and generally does not exceed 30 meters. The southern half of the bay is bordered on the east by the Tertiary Bōsō Penninsula and on the west by Tertiary hills of the Miura Penninsula. The northern half is surrounded by the wide alluvial Kanto Plain. The bay is generally calm in contrast to the high waves of the Gulf of Sagami of which sediment distribution was described in the foregoing paper (Nasu, 1956 a).

Several rivers empty into the bay from all directions. Among these, the Tama, Edo (Murai, 1956), Yoro, Obitsu, and Koito Rivers form deltas. The tidal flat along the coast of the Tokyo Bay consists of sand or sand-mud mixtures. In general the mud content is higher along the west coast than along the east. A few areas of sand dunes can be seen along the east coast of the bay due to the prevailing westerly winds.

There is a short steep gradient in the upper and middle regions of the Obitsu River, but the gradient suddenly decreases when the river comes into the delta. So

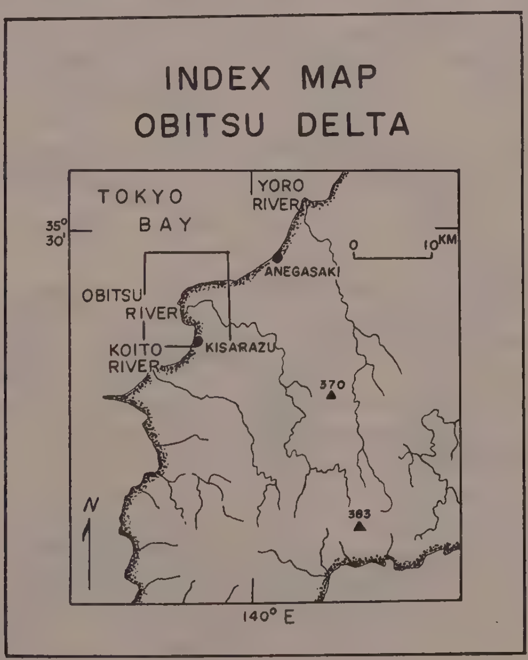

Fig. 2.

far there are no data available about the discharge of the river; however, according to the writers' observation, there was no apparent outflow at its mouth during low tide except during the periods of precipitation.

The Obitsu Delta, a typical small scale delta in the Chiba Prefecture, Japan,

has top-set, fore-set, and bottom-set beds (Figs. 2 & 3). The top-set bed is divided into a subareal plain and a subaqueous plain; and a shore face which divides one from the other extrudes into Tokyo Bay forming a fan-shaped coast line.

A tidal flat is a part of the subaqueous plain just off the shore side of the shore face. A shallow and very gently tilted surface spreads over beyond the tidal flat. The edge of this flat, shallow top-set bed shows a fan-shape parallel to the shore face. A steep slope occurs beyond the edge, and it is called fore-set bed, or marginal slope here. A flat bottom-set bed occupies the area beyond this fore-set bed and maintains the original submarine configuration.

Tertiary sedimentary rocks cover the entire drainage area of the river (Fujita and Suyama, 1952; Koike, 1951; Sakakura, 1935).

Topography

The Obitsu River has built a semi-circuler delta extending about four kilo-

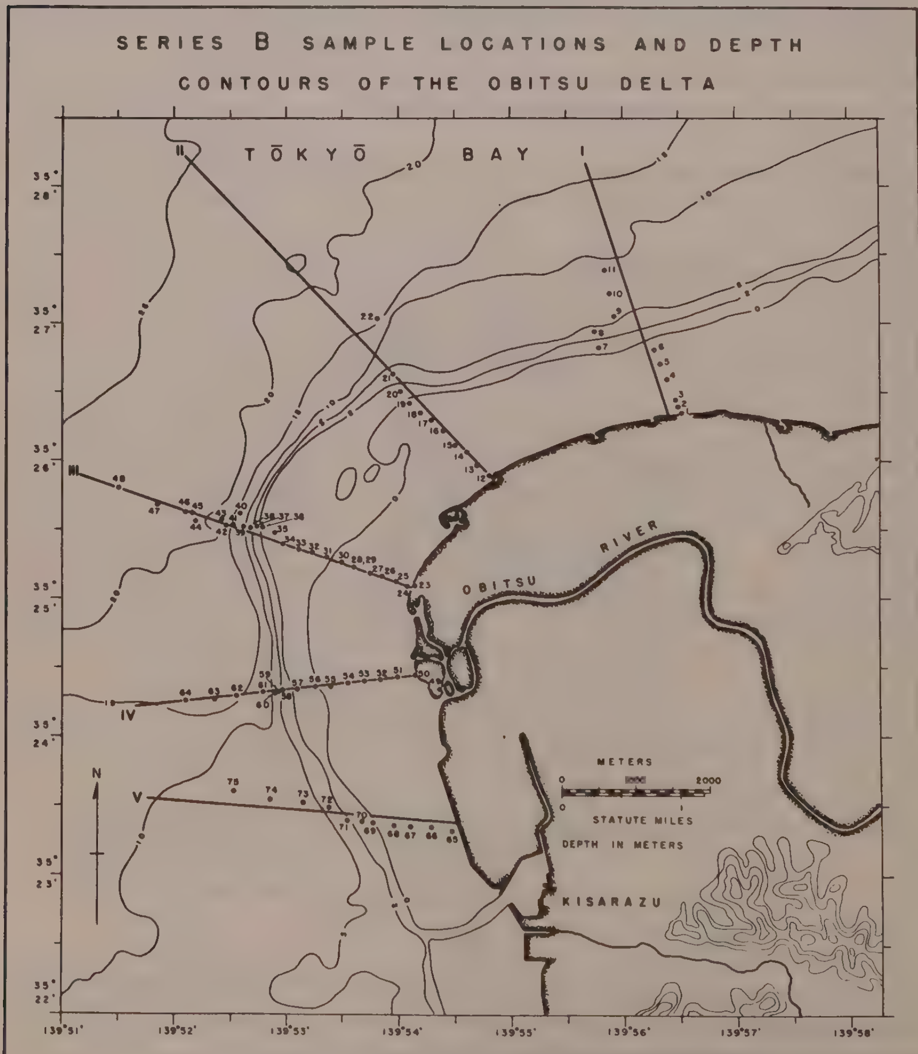

Fig. 3.

meters into Tokyo Bay with a diameter of about eight kilometers where it joins the coast (Fig. 3).

The subareal part of the delta is cultivated and covered by rice fields and is spotted by a few villages. The shore face, which separates the tidal flat from the higher subareal portion, consists predominantly of sand. Along this shore line there were a few scattered houses which probably influence the pattern of sediment distribution.

The tidal flat is 1200 meters wide on the average along the coast and is covered by sea water during high tides. The outer edge of this tidal flat was defined as the zero depth contour and corresponds to Indian Spring Low Water. The spring range of tide in Tokyo Bay is approximately 1.5 meters.

The water depths bayward from this contour were based on Hydrographic Chart No. 1062 (Surv. Hydro. Depart. Japan, 1936), and also on the depth records obtained at each sampling location of this survey. The contour lines of 0, 2, 5, 10, 20 and 25 meters are drawn in Figure 3. The 0, 2 and 5 meter contours run parallel to the shore line of the delta and extend out into Tokyo Bay. The 20 and 25 meter contours are concave towards the center of the bay and seem to reflect the original configuration of Tokyo Bay.

Five profiles of the delta, together with the size distribution measures for the sediments, are illustrated in Figure 4. There is a wide, flat area between the shore and the 2 meter depth contour. This tidal flat area will be referred to as the top-set bed. Along profiles II, III and IV, the bottom slopes rapidly from 2 meters to 15 meters. This part will be referred to as the fore-set bed. Along profiles I and V the bottom slopes from 2 meters to 5 meters rapidly, but becomes gentle in deeper water, perhaps due to greater distance from the central part of the delta. The relatively flat bottom extending bayward from the fore-set bed will be referred to as the bottom-set bed.

The recent river mouth opens at the base of profile IV. However, it is reasonable to assume that the river course has migrated over the whole area of the delta during the past.

Field Observations

During the course of the survey the following observations were made on the top-set bed or tidal flat of the delta.

(1) Ripple marks were common and well developed. (2) Small attached algae covered wide areas, occupying 100 meters wide from the shore face in the northern part of the delta expanding to several hundred meters wide towards the southern part. (3) Bottom sediments consisted largely of well sorted sands. (4) The bottom had slight undulations with a maximum relief of about thirty centimeters. (5) Shell fragments were concentrated at several places forming massive shell beds sorrounded by the ordinary well sorted sands, perhaps due to the vortex flows occurred in the tidal currents (Kimura, 1955). (6) Mixed sediments of sand and mud were observed and collected close to the river mouth.

Along the fore-set and bottom-set beds the following conditions were observed.

(7) In general, well sorted sands were obtained from depths shallower than 10 meters. (8) Muddy sediments which were distinctly different from the sandy meterial of the top-set bed were found at depths greater than 15 meters. (9) Currents were flowing toward the northeast at the surface over the fore-set bed during the survey. Of course, the velocity fluctuated from almost zero to several tens of centimeters

per second depending upon the stage of the tide. (10) *Umbonium* and shell fragments were abundantly found on the lower half of the fore-set bed.

Particle Size Distributions

The results of the particle size distribution analyses are listed in Table I in the appendix and their interpretation is discussed below.

Phi median diameter Md_ϕ, phi deviation measure σ_ϕ, and phi skewness measure α_ϕ of each location are plotted along each profile of the delta in Figure 4, as mentioned previously. Facts as illustrated in this figure are the following.

(1) Along profiles III and IV, which show more distinct deltaic configuration than the other three, sediment distribution measures maintain stable and constant values in each topographical feature of top-set, fore-set and bottom-set beds, but

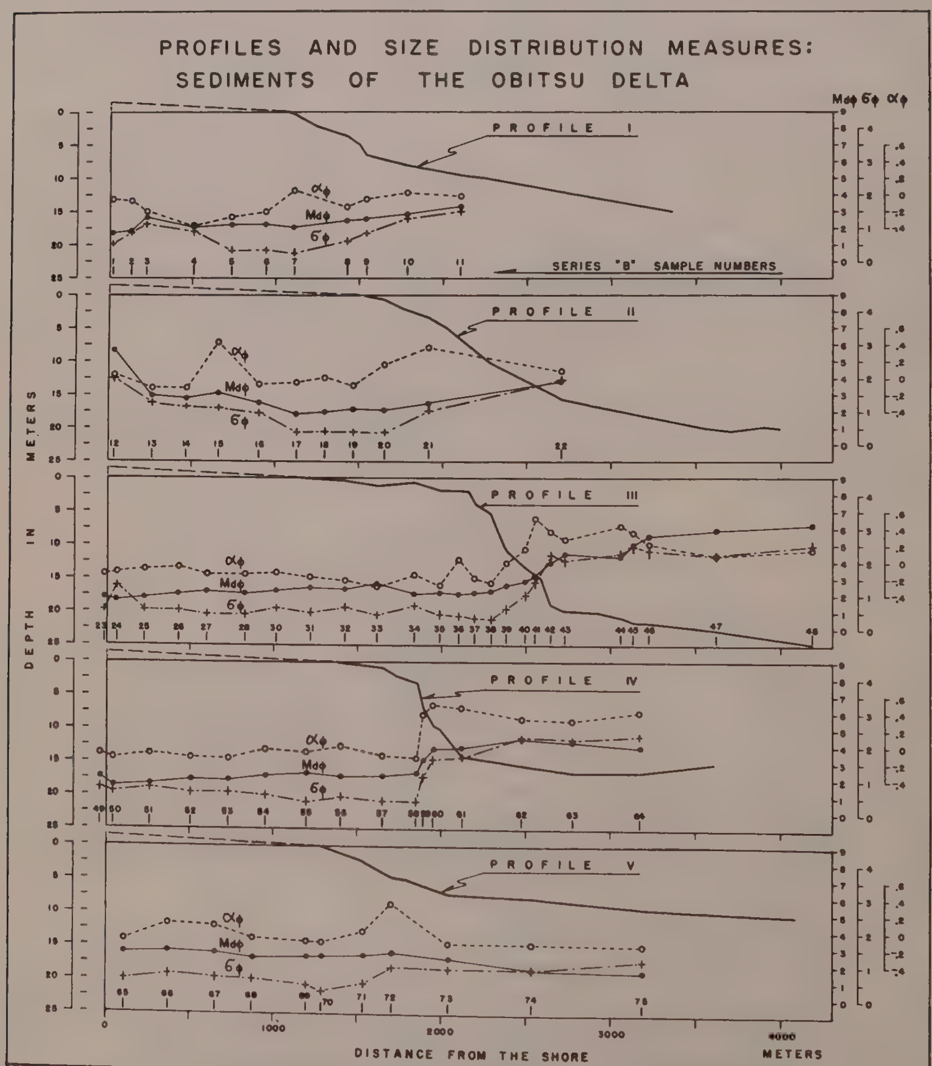

Fig. 4.

indicate evident distinction between them.

(2) On the contrary, sediment distribution measures along profiles I, II and V indicate a rather gradual variation of sediment types along the profiles.

Each value of size distribution measures is plotted on the abscissa and the depth on the ordinate in Figure 5. Interpretations from this figure are the following.

(3) Median diameter stays in a range between 1.5ϕ to 3ϕ (medium to fine sand) down to the depth somewhere between 5 and 10 meters (the top-set bed and the upper half of the fore-set bed), then gradually becomes finer through the fore-set to the bottom-set beds.

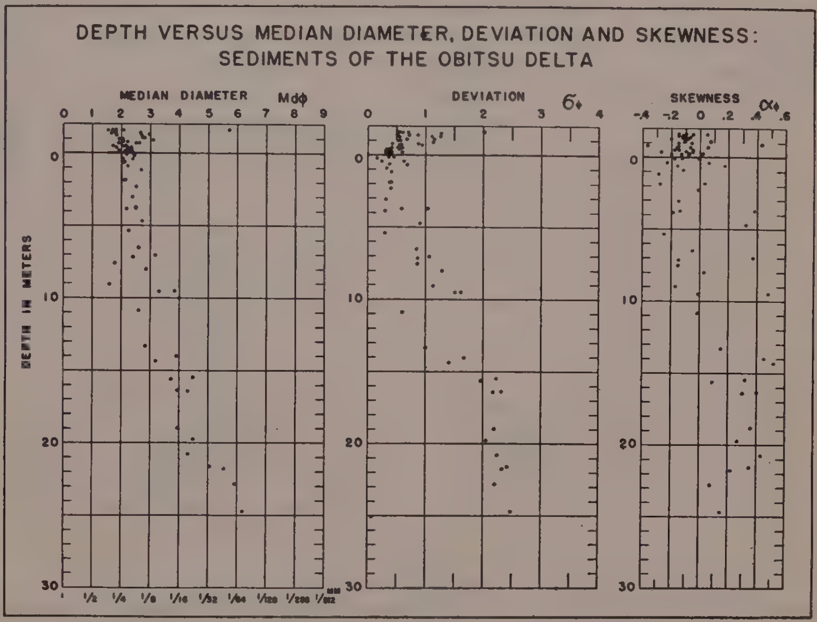

Fig. 5.

(4) Phi deviation measure σ_ϕ indicates the best sorting near zero water level and down to the depth of 3 meters. Toward the shore face from the outermost margin of the tidal flat (zero water level) the phi deviation measure increases in value, indicating a gradual trends towards poorer sorting. From 3 to 15 meters depth, along the slope of fore-set bed, the sorting becomes worse, then it is fairly stabilized after passing the 15 meter contour to the bottom-set bed. The occurrence of low σ_ϕ values at the outer edge of the tidal flat probably results from the sorting action of waves.

(5) Phi skewness measures α_ϕ are quite scattered in this diagram. Comment regarding this fluctuation is reserved to the discussion of the following figure.

Finally, σ_ϕ and α_ϕ values are plotted as a function of Md$_\phi$, which is shown in Figure 6. This figure illustrates the following conclusions.

(6) The best sorted sediments (lowest values of σ_ϕ) are those with median diameter between about 2ϕ to 2.5ϕ, and the coarser or finer sediments are poorer sorted.

(7) For median diameters in the range of 1.5ϕ to 2.5ϕ, the skewness as indicated by α_ϕ is distributed between -0.3 and zero. As the median increases to 3ϕ to 4ϕ,

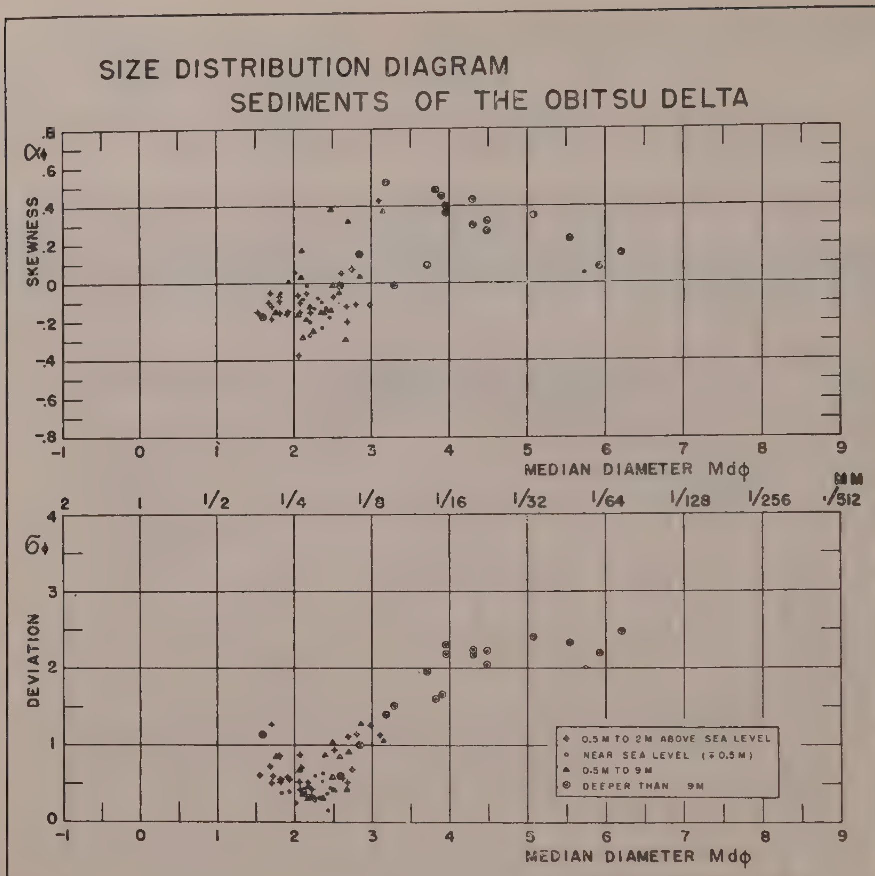

Fig. 6.

the skewness jumps to positive values of about 0.5, then gradually decreases toward zero with increasing values of Md_ϕ.

Constituents

The results of coase fraction analyses of a few representative samples as shown in Table II indicate that, as in the case of the Sagami River sediments (Nasu, 1956a), the terrigenous materials are definitely dominant in this area.

The results of mineral grain analyses of the same samples as shown in Table III show that light minerals are dominant and the constituents do not suggest the existence of metamorphic rocks in its source area of the Obitsu River.

The further discussion of the methods of coarse fraction analyses and mineral grain analyses has already been described, the readers are referred to Shepard and Moore (1954), and Nasu (1956a, pp. 80–82).

The composition of the sand size fraction of a typical sample would be about as follows:

% by weight	*Composition*
88	Feldspar and quartz
4	Rock fragments
8	Heavy minerals, predominantly augite, hornblende, hypersthene and miscellaneous opaque minerals.

Although only a few samples were investigated, the characteristics of Foraminifera at the location of B–24 (*Rotalia beccarii* (Linné), *Trochammina inflata* (Montagu), and B–46 (*Nonion manpukujiense* Otuka, *Rotalia japonica* Hada) reflect good agreement with the environments so far.

Hydrodynamics

It is desirable to discuss briefly a few known principles of hydrodynamics before entering into the interpretation of the sedimentological field facts. However, this part of the problem has already been discussed by the senior author (Nasu, 1956a, pp. 82–90), so that a brief summary will be referred here.

The settling velocities of sand and gravel are fast, so the settling durations are short. In the silt-clay size, the settling velocity slows down acceleratedly in accordance with the decrease of the grain size, therefore, the settling duration becomes much longer than that for sand or gravel. (Fig. 7).

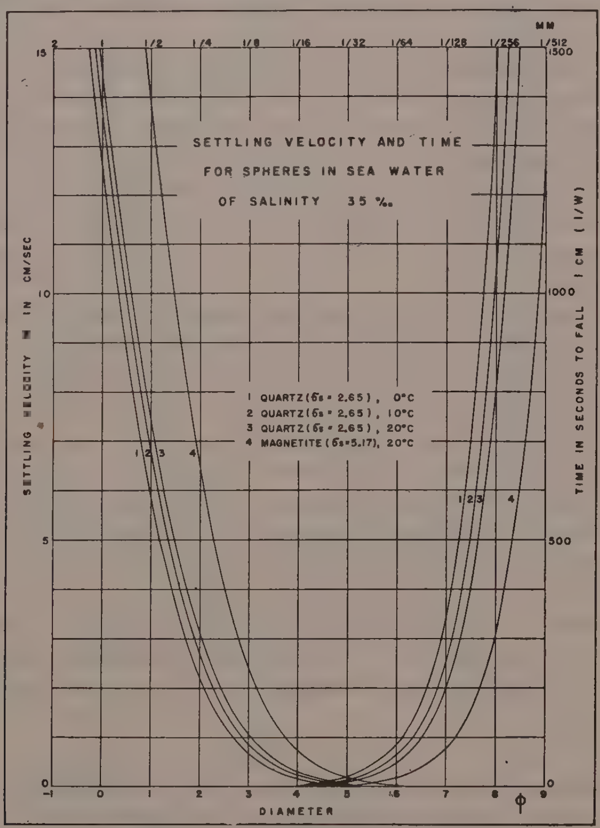

Fig. 7. (after Nasu, 1956a, P. 84)

Because, the resistance force acting upon a particle caused by water is mostly due to the viscosity, i. e., surface friction in a range of silt-clay fractions; instead, that acting on sand or on gravel is mainly derived from the form-drag, namely, the pressure differences between the front and the back of a particle in the settling direction.

The flow contains turbulence generally. Vertical water mass exchange due to this turbulence tends to postpone the duration of suspension of sediments. The stronger the tubulence is, the longer the duration will be when the particle size is constant. The smaller the size is, the stronger this iefluence will be when the intensity of turbulence stays constant. Therefore, silt-clays have more chances to be suspended in water.

The threshold mean flow velocity of the bottom sediments is minimal at sand size. It is approximately 15 cm/sec in case of the Hjulström's observation (Hjulström, 1939, p. 10, Fig. 1, or Nasu, 1956a, p. 87, Fig. 10). One possible cause of such an effect may be the existence of the bottom laminar boundary layer when the bottom surface consists of silt-clay materials. Because the bottom laminar boundary layer will keep the turbulence from reaching the very bottom, and also because the horizontal velocity will be very slight at this height, the particles small enough to be hidden in this layer will not be moved so easily.

Therefore, the settled silt-clays do not start to move at the velocity in which sands initiate their motion. According to the increase of the velocity, the finer sediment will be plucked into water because of the increase of turbulent intensity which reaches the bottom more often than before. On the shallow bottom of the top-set bed, the flow velocity caused by waves, tidal current and wind-stressed current will be strong enough to pluck the muddy sediments into suspension, while the flow condition on the bottom-set bed may be much closer to the stagnant one. Once being in suspension, silt-clays will stay in water for long duration due to their slow settling velocity emphasized by the vertical mass exchanges of water due to the turbulence. If there is any horizontal advection, they will be transported for a long distance quite easily.

Sands are the easiest to shift, but the settling velocity is so fast that they settle back to the bottom quickly and the influence caused by the turbulence will not be as strong as in silt-clays. Therefore, they will tend to stay close to the bottom. Their transportation will be in the forms of saltation, bed load and bottom surface creep (Inman, 1949, p. 61).

Gravels are hard to shift and the settling velocity is large, so they will tend to stay and distribute within certain limited areas.

The most important fact is that there is a tendency between gravels, sands and silt-clays to separate from each other during the processes of transportation due to the hydrodynamical reasons mentioned here; i.e., sorting will take place. This separation is not dependent upon a special kind of fluid movement, but it is simply due to the common processes of fluid motion which are going on in nature very commonly. Also, the motion type will be different in different types of sediments; for example, sands may take the creeping style, while silt-clays may be in suspension.

The Occurrence of the Steep Marginal Slope of the Obitsu Delta

The profiles shown in Figure 4 and the areal topography of Figure 3 evidently present a small scale delta. At profiles II, III, IV in the central portion of the delta, the top-set bed runs to about the two meters depth, then the fore-set bed ends at a depth of fifteen to twenty meters and the bottom set bed is found beyond this. The sediments on the top-set bed are typically well sorted medium and fine sands (Figs. 4 and 5).

The fore-set bed sediments are well sorted fine sands on the upper half and

start to indicate the increase of mud content on the lower half. The bottom-set sediments are significantly muddy and the sorting measure σ_ϕ is larger than 2. The transition from sands to muds will take palce at the base of the fore-set bed in a narrow area. Along profiles I and V all of the collected samples are medium and fine sands. Here, the fore-set bed shows a steep alope only to the depth of five meters; beyond this depth it slopes gently to a depth of twenty meters.

The possible processes of formation of the Obitsu Delta are outlined below on the basis of the foregoing statements.

(1) The transporting power of the Obitsu River is usually small and does not carry much sediments into Tokyo Bay.

(2) Plentiful amount of sediments are supplied sporadically from the river mouth to the delta surface during the floods.

(3) Sands reach the river mouth creeping along the bottom or in suspension because of the intense turbulence of the flowing river water. Since the settling rate of sands are fast, they settle to the bottom soon after the river water starts to spread over the delta surface and decreases its velocity. However, they still keep their shifting motion along the shallow bottom because of exceeding current velocities in comparison with their threshold mean flow velocities, caused by waves, tides, and other movements of water mass along the surface of the top-set bed. Sands which are carried out of the top-set bed slide down over the upper part of the fore-set slope and contribute to the horizontal expansion of the main body of the delta.

(4) Silt-clays settle to the bottom after passing by the top-set bed in suspension by the advections and the horizontal water mass exchanges. Of course, a part of them will settle on the top-set bed once in a while, but will be carried away before long by the action of waves, tides and currents because of shallow depth of the top-set bed.

(5) Rice fields are being cultivated over the whole area of the subareal plain of the delta. The banks of the main stream of the Obitsu River are reinforced to prevent flooding. Prior to these artificial modifications, the main stream as well as tributaries might have changed their courses all over the subareal plain. Thus, the river mouths might have changed their positions along the shore face. Therefore, it is easily speculated that the sediments supplied by the Obitsu River as well as the Paleo-Obitsu River might have been scattered evenly to all directions.

(6) There are no gravels on the subaqueous plain. If they existed, they might be deposited before reaching the present position of the river mouth.

(7) In conclusion, the sediments supplied from the river mouth have been sorted into sands and muds. The sands were deposited very close to the mouth forming a fan-shaped main body of the delta, of which surface has been leveled by waves, tides and current actions. This is the top-set bed, and beyond its margin, the main body of the delta ends by forming a steep marginal slope which is somewhat similar to the repose angle of sandy sediments in water; the angle of this slope may depend upon the grain size of the sediments, wave heights, intensity of currents and supply amounts of sediments. In other words, the main body of the Obitsu Delta might have resulted from the concentration of sands. On the other hand, muds have been carried into Tokyo Bay proper, and a part of them has formed the bottom-set bed beyond the fore-set bed.

(8) Therefore, the separation of sands and muds will result in forming a delta at a river mouth when it enters a calm, shallow sea like Tokyo Bay, and the marginal slope can be looked upon as a narrow transition zone which draws a margin between sandy and muddy areas.

(9) On the other hand, for example, along the open coast of the Gulf of Sagami where strong waves as well as longshore currents wash the shore, the muds are apparently diffused towards offshore, the sands are shifted along the shore, and a part of them will fall into the submarine canyon of which the head is situated close to the river mouth. Thus, there is no room to form delta at the river mouth. For this reason, the transition zone between sandy and muddy areas is presented here by a sharp boundary at the depth of twelve meters parallel to the shore (Nasu, 1956 a).

(10) As the above mentioned statements are based upon the phenomena controlled by the general principles of hydrodynamics, these may also be applied with caution as the forming process of the steep marginal slope of deltas elsewhere.

Summary and Conclusions

It is well known that sediments are commonly separated into sand and mud fractions during the common processes of transportation and deposition as a result of a few established principles in hydrodynamics.

The significance and geologic importance of this separation reflected by the actual distribution of modern sediments of the Obitsu Delta in Tokyo Bay has been discussed, and the occurrence of the steep marginal slope of a small scale delta has been explained (Fig. 2).

Principally, three measures of phi median diameters, Md_ϕ, phi deviation measures, σ_ϕ, and phi skewnness measures, α_ϕ, obtained from particle size distribution curves of the collected sediments have been used for the interpretation (Fig. 1).

Among the findings by field obeservations as well as by the results of sedimentary analyses, the followings are important.

(1) The subareal plain of the delta has a base of eight kilometers in diameter and extends approximately four kilometers into Tokyo Bay which in general is shallower than thirty meters. The subaqueous plain of the top-set bed consists mostly of a tidal flat which surrounds the shore face. The width of the tidal flat is approximately 1200 meters.

(2) The major part of the delta shows a typical profile consisting of top-set, fore-set, and bottom-set beds. The fore-set bed occupies the depth range between two meters and fifteen to twenty meters, and has a steep marginal slope. The bottom-set bed of mild gradient extends beyond the base of the fore-set bed (Figs. 3 & 4).

(3) Well sorted medium to fine sands occupy the surface of the top-set bed and the upper half of the fore-set bed. The lower half of the fore-set bed consists of a mixture of sand and mud and it forms a narrow, arcuate band surrounding the outer skirt of the delta. The bottom-set bed consists of mud mostly. Therefore, the main body of the delta probably consists of well sorted sands in general. The fore-set bed, especially its lower half, can be considered as a narrow transition zone between sand and mud distribution ranges.

(4) As seen in Figure 5, the sorting of the sediments is the best at the outer edge of the tidal flat to the depth of three meters, most likely due to the wave action along the surf zone. Toward the inner portion of the tidal flat, the sorting values increase slightly, while to the bottom-set bed through the deeper portion of the fore-set bed the values suddenly increase.

(5) Throughout the investigations of this area, there existed some characteristic tendencies in the relations between median diameters and skewness values of the

sediments, as seen in Figures 4, 5, and 6; namely, (a) the sorting values are least when the median diameters are around 2ϕ, and (b) the skewness values tend to be negative when the phi median diameters are less than 3ϕ, then suddenly increase toward large positive values when the phi median diameters approach 4ϕ. When the phi median diameters exceed 4ϕ, α_ϕ values decrease gradually toward zero, in general. These tendencies are not only shown in the present result, but have been common in previous works. These are the major results obtained from the investigations over the area.

Since settling velocity of mud is quite slow, it is suspended in water for a long period and is transported for a long distance. The settling velocity of sand, on the contrary, is very fast, because the resistance from the water is not only caused by the viscosity but also by the form-drag.

The turbulent boundary layer of water has a bottom laminar boundary layer when the bottom is smooth. Muddy bottom will be considered smooth when silt-clay do not project above this thin laminar layer and thus have rare chances to be plucked into water by the vertical component of turbulence. In addition, the coagulation effect of muds will tend to make difficult the initiation of motion of muds by weak currents.

Gravels are not easily shifted simply due to their weight. Thus, medium to fine sands are most easily shifted by the weakest current, namely the threshold mean flow velocity is minimal in medium to fine sand, because at this stage of the bottom condition, the bottom laminar boundary layer may not exist any longer and sediments will be plucked into water easily by the vertical component of turbulence and also will be moved by the horizontal force of the currents.

Therefore, gravels, sands, and muds will be separated from each other during the processes of transportation, for example, at a river mouth, and the major style of sand motion will be a sheet flow or saltation along the bottom and that of muds will be in suspension.

Therefore, among the sediments supplied from the mouth of the River Obitsu, sand fractions settle to the bottom quickly soon after they reach the outside of the mouth. The small waves of Tokyo Bay and the moderate tidal currents shift those fractions generating and forming a flat, shallow bottom of the tidal land, while the waves and the currents are rough enough to churn up the muds deposited temporarily on the tidal flat. Mud fractions on the bottom, therefore, are put into suspension and scattered to the offshore by the horizontal water exchanges, and are not able to remain on the tidal flat. Thus, only the well sorted medium to fine sands having fairly constant median diameters are able to stay on the tidal flat.

Gravels might be deposited in a range of the subareal part of the delta. Thus, a typical delta having top-set, fore-set, and bottom-set beds would be formed. The main body of the delta, surrounded by the top-set bed and the upper half of the fore-set bed, is composed of dominantly sandy sediments so that it forms a fairly steep marginal slope which may be considered as a kind of repose angle of sand pile in water. Muds predominate beyond the foot of the fore-set bed, thus the median diameter suddenly becomes finer and the sorting values become larger.

The sudden change of skewness values from negative to positive when the median diameters are between 3ϕ to 4ϕ, which is close to the boundary between sands and muds is probably due to the separation of sands and muds during the course of transportation.

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Appendix

Table I. Data on Particle Size Distribution of Series B Samples Sediments of the Obitsu Delta

(Samples above chart sea-level shown with minus sign in depth column)

Sample No.	M_ϕ	Md_ϕ	σ_ϕ	α_ϕ	β_ϕ	$\alpha_{2\phi}$	% Sand	% Silt	% Clay	Sampling Date	Depth in Meters	Remarks
B—1	1.67	1.70	0.51	−0.05	0.68	−0.15	99	1	0	1950-7-26	−1.6	
B—2	1.74	1.81	0.87	−0.07	1.76	0.79	92	6	1	1950-7-26	−1.4	
B—3	2.47	2.69	1.11	−0.20	0.68	−0.55	95	3	1	1950-7-26	−1.3	
B—4	1.74	2.07	0.88	−0.37	0.91	−0.62	97	1	0	1950-7-26	−0.8	
B—5	2.12	2.21	0.33	−0.27	1.04	−0.95	99	0	0	1950-7-26	−0.4	
B—6	2.15	2.22	0.32	−0.20	0.86	−0.57	100	0	0	1950-7-26	−0.2	
B—7	2.03	2.02	0.25	0.06	0.71	0.14	100	0	0	1950-7-26	0.4	
B—8	2.41	2.49	0.59	−0.14	1.31	0.21	94	4	1	1950-7-26	3.7	
B—9	2.54	2.58	0.85	−0.05	1.23	0.19	91	6	2	1950-7-26	6.5	
B—10	2.89	2.85	1.28	0.03	1.30	0.54	80	17	3	1950-7-26	8.0	
B—11	3.28	3.29	1.52	−0.01	1.66	0.20	63	29	4	1950-7-26	9.5	
B—12	5.83	5.73	2.01	0.05	0.66	0.16	20	65	15	1950-7-28	−1.6	
B—13	2.84	2.98	1.26	−0.11	1.21	0.36	85	12	3	1950-7-28	−1.3	
B—14	2.67	2.80	1.15	−0.11	0.90	0.14	89	10	1	1950-7-28	−1.1	
B—15	3.59	3.10	1.13	0.43	1.06	1.00	76	22	2	1950-7-28	−0.9	
B—16	2.44	2.51	0.95	−0.07	1.50	0.73	91	7	2	1950-7-28	−0.7	
B—17	1.81	1.83	0.38	−0.05	0.67	−0.09	100	0	0	1950-7-28	−0.4	
B—18	1.93	1.93	0.41	0.01	0.81	0.02	100	0	0	1950-7-28	−0.2	
B—19	2.09	2.12	0.38	−0.08	0.76	−0.11	100	0	0	1950-7-28	−0.1	
B—20	2.16	2.10	0.38	0.17	0.70	0.32	100	0	0	1950-7-26	0.6	
B—21	2.88	2.49	1.04	0.38	1.29	1.25	85	13	2	1950-7-26	3.7	
B—22	3.88	3.71	1.96	0.09	0.96	0.63	57	35	7	1950-7-26	15.6	
B—23	1.73	1.82	0.55	−0.15	0.89	−0.49	99	0	0	1950-7-27	−1.6	beach
B—24	1.55	1.71	1.27	−0.12	2.00	−0.07	84	8	1	1950-7-27	−1.5	
B—25	1.77	1.82	0.55	−0.09	0.78	−0.27	100	0	0	1950-7-27	−1.3	
B—26	2.03	2.06	0.53	−0.06	0.87	−0.13	99	1	0	1950-7-27	−1.0	
B—27	2.15	2.22	0.43	−0.15	0.80	−0.42	100	0	0	1950-7-27	−0.8	
B—28	2.01	2.08	0.42	−0.15	0.81	−0.38	100	0	0	1950-7-27	−0.5	
B—29	1.60	1.71	0.60	−0.18	0.70	−0.52	100	0	0	1950-7-27	−0.5	
B—30	2.19	2.27	0.60	−0.13	1.57	−1.13	96	0	0	1950-7-27	−0.2	
B—31	2.38	2.46	0.45	−0.18	1.47	−0.64	99	1	0	1950-7-27	0.1	
B—32	2.22	2.37	0.63	−0.23	0.96	−0.76	99	0	0	1950-7-27	0.4	
B—33	2.55	2.67	0.42	−0.29	0.94	−0.63	99	1	0	1950-7-27	1.2	
B—34	1.95	2.06	0.68	−0.16	0.68	−0.44	100	0	0	1950-7-27	0.6	
B—35	2.00	2.12	0.41	−0.28	0.57	−0.43	100	0	0	1950-7-27	1.8	
B—36	2.10	2.09	0.38	−0.08	0.72	−0.28	100	0	0	1950-7-27	1.8	
B—37	2.11	2.17	0.31	−0.19	0.82	−0.47	100	0	0	1950-7-27	3.8	
B—38	2.16	2.24	0.30	−0.25	0.85	−0.61	100	0	0	1950-7-27	5.4	
B—39	2.58	2.59	0.60	−0.01	1.52	0.47	93	6	0	1950-7-27	10.8	
B—40	2.99	2.84	1.00	0.15	2.25	0.51	80	13	3	1950-7-27	13.3	
B—41	3.91	3.18	1.41	0.52	0.96	1.12	74	22	4	1950-7-27	14.4	
B—42	4.73	3.95	2.19	0.36	0.76	0.87	51	40	9	1950-7-27	18.8	
B—43	5.03	4.48	2.05	0.27	0.85	0.91	44	46	10	1950-7-27	19.8	
B—44	5.26	4.30	2.24	0.43	0.70	0.71	46	41	13	1950-7-27	20.8	
B—45	5.90	5.07	2.41	0.35	0.50	0.54	26	56	18	1950-7-27	21.6	
B—46	6.06	5.54	2.33	0.22			32	49	19	1950-7-27	21.8	
B—47	6.10	5.92	2.20	0.08			21	61	18	1950-7-27	22.8	

Sample No.	M_ϕ	M_ϕ	σ_ϕ	α_ϕ	β_ϕ	$\alpha_{2\phi}$	% Sand	% Silt	% Clay	Sampling Date	Depth in Meters	Remarks
B—48	6.56	6.20	2.48	0.15	0.46	0.15	15	58	27	1950-7-27	24.7	
B—49	2.01	2.08	0.71	−0.10	0.96	−0.18	96	3	0	1950-7-29	−1.6	beach
B—50	1.45	1.54	0.61	−0.15	0.71	−0.39	100	0	0	1950-7-29	−1.6	beach
B—51	1.60	1.68	0.72	−0.10	0.74	−0.31	99	0	0	1950-7-29	−1.4	
B—52	1.84	1.93	0.56	−0.15	0.71	−0.38	100	0	0	1950-7-29	−1.0	
B—53	1.81	1.91	0.58	−0.16	0.78	−0.46	100	0	0	1950-7-29	−0.7	
B—54	2.14	2.17	0.52	−0.05	0.75	−0.21	99	1	0	1950-7-29	−0.5	
B—55	2.29	2.32	0.32	−0.08	1.03	−0.15	100	0	0	1950-7-29	−0.2	
B—56	2.16	2.17	0.46	−0.01	0.80	0.01	99	1	0	1950-7-29	0.1	
B—57	2.16	2.20	0.33	−0.12	0.86	−0.14	100	0	0	1950-7-29	0.9	
B—58	2.30	2.35	0.32	−0.16	0.86	−0.32	100	0	0	1950-7-29	3.0	
B—59	3.54	3.15	1.07	0.37	1.20	1.11	79	29	2	1950-7-29	7.0	
B—60	4.59	3.82	1.61	0.48	0.86	1.14	59	33	8	1950-7-29	9.5	
B—61	4.65	3.90	1.67	0.45	0.82	1.09	60	32	8	1950-7-29	14.0	
B—62	5.20	4.48	2.23	0.32	0.70	0.70	45	43	12	1950-7-29	15.4	
B—63	4.96	4.30	2.18	0.30	0.73	0.60	48	42	10	1950-7-29	16.4	
B—64	4.88	3.95	2.31	0.40	0.72	0.63	52	37	11	1950-7-29	16.4	
B—65	2.62	2.68	0.51	−0.12	1.23	0.00	98	1	0	1950-7-30	−1.4	
B—66	2.78	2.74	0.68	0.07	0.87	−0.09	93	5	0	1950-7-30	−1.1	
B—67	2.65	2.62	0.57	0.05	0.97	0.27	96	3	0	1950-7-30	−0.7	
B—68	2.30	2.36	0.54	−0.10	1.51	−0.72	95	2	0	1950-7-30	−0.4	
B—69	2.37	2.42	0.37	−0.13	1.03	−0.30	100	0	0	1950-7-30	0.1	
B—70	2.40	2.43	0.17	−0.14	1.34	−0.11	100	0	0	1950-7-30	0.2	
B—71	2.49	2.50	0.41	−0.01	0.87	0.01	99	1	0	1950-7-30	2.3	
B—72	2.99	2.70	0.91	0.32	1.47	1.46	86	13	1	1950-7-30	4.7	
B—73	2.25	2.39	0.87	−0.15	3.01	0.79	85	9	2	1950-7-30	7.2	
B—74	1.64	1.77	0.86	−0.15	2.96	1.05	87	7	1	1950-7-30	7.6	
B—75	1.40	1.59	1.13	−0.17	2.68	0.52	85	6	2	1950-7-30	9.0	

Note: The values of M_ϕ, β_ϕ, and $\alpha_{2\phi}$ are also tabulated here in the interest of completness (Inman, 1952, pp. 130-138, or Nasu, 1956 a, pp. 71-72.)
The percentage of gravel is not indicated here, because it is easy to calculate by subtracting from 100% the total percentage of the sediments tabulated.

Table II. Composition of the Coarse Fraction of Representative Samples.

Sample No. B—24

Size fraction, ϕ	<−2	−2 to −1	−1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	<4
Fractional weight, %	5.2	1.8	5.2	21.8	24.0	29.0	4.0	91.0
shell fragments	1.0	0.7	0.4	0.7	tr	0	tr	2.8
Foraminifera	0	0	0	0	0	tr	tr	tr
diatoms	0	0	0	0	0	tr	0	tr
ostracods	0	0	0	0	0	tr	tr	tr
glauconite	0	0	0	0	0	0	0	0
echinoid fragments	0	0	0	0	0	tr	0	tr
plant fibers	0	0	0	0	tr	0.3	0.1	0.4
terrigenous non-dark minerals	0	0.6	3.5	14.5	19.2	24.4	3.7	65.9
terrigenous dark minerals	0	0	0	0.9	1.9	2.9	0.2	5.9
terrigenous rock fragments	4.2	0.5	1.3	5.7	2.9	1.4	0	16.0
terrigenous mica	0	0	0	0	0	tr	tr	tr

Sample No. B−30

Size fraction, ϕ	<−2	−2 to −1	−1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	<4
Fractional weight, %	0.0	0.0	5.0	4.0	24.0	59.0	8.0	100.0
shell fragments	0	0	2.5	0.1	0.2	0	0	2.8
Foraminifera	0	0	0	0	0	0	0	0
diatoms	0	0	0	0	0	0	0	0
ostracods	0	0	0	0	0	0	0	0
glauconite	0	0	0	0	0	0	0	0
echinoid fragments	0	0	0	0	0	0	0	0
plant fibers	0	0	tr	0	tr	tr	0	tr
terrigenous non-dark minerals	0	0	1.3	2.6	20.6	54.9	7.6	87.0
terrigenous dark minerals	0	0	0.2	0.1	0.8	1.1	0.4	2.6
terrigenous rock fragments	0	0	1.0	1.2	2.4	3.0	0	7.6
terrigenous mica	0	0	0	0	0	0	0	0

Sample No. B−38

Size fraction, ϕ	<−2	−2 to −1	−1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	<4
Fractional weight, %	0.0	0.0	0.2	0.8	24.0	74.5	0.5	100.0
shell fragments	0	0	0.1	tr	0	0	0	0.1
Foraminifera	0	0	0	tr	0	0	0	tr
diatoms	0	0	0	0	0	0	tr	tr
ostracods	0	0	0	0	0	0	0	0
glauconite	0	0	0	0	tr	0	0	tr
echinoid fragments	0	0	0	0	0	0	0	0
plant fibers	0	0	0	0	0	0	tr	tr
terrigenous non-dark minerals	0	0	0	0.7	22.8	70.8	0.5	94.8
terrigenous dark minerals	0	0	0	tr	0.5	3.7	tr	4.2
terrigenous rock fragments	0	0	0.1	0.1	0.7	0	0	0.9
terrigenous mica	0	0	0	0	0	0	0	0

Sample No. B−46

Size fraction, ϕ	<−2	−2 to −1	−1 to 0	0 to 1	1 to 2	2 to 3	3 to 4	<4
Fractional weight, %	0.0	0.0	0.2	0.2	1.2	4.9	25.5	32.0
shell fragments	0	0	tr	tr	tr	0.1	tr	0.1
Foraminifera	0	0	0	0	tr	tr	0	tr
diatoms	0	0	0	0	0	tr	0	tr
ostracods	0	0	0	0	tr	0	0	tr
glauconite	0	0	0	0	0	0	0	0
echinoid fragments	0	0	0	0	tr	tr	tr	tr
plant fibers	0	0	0	0	tr	tr	tr	tr
terrigenous non-dark minerals	0	0	0.1	0.1	0.6	4.2	23.7	28.7
terrigenous dark minerals	0	0	0	tr	0.2	0.3	1.0	1.5
terrigenous rock fragments	0	0	0.1	0.1	0.4	0.3	0.8	1.7
terrigenous mica	0	0	0	0	0	tr	tr	tr

Notes: The number for each constituent present the percentage of the entire sample. Here, "tr" means trace.

Table III. Data on Mineral Grain Analyses of the Representative Samples

Sample No.	Size fraction ϕ	Heavy Minerals			Light Minerals				
		% mono-minerals	% rock fragments	% other constituents	% mono-minerals	% rock fragments	% other constituents	% Heavy minerals by wt.	% Light minerals by wt.
B−24	1–4	95	2	3	70	23	7	10.4	89.6
B−30	1–4	95	2	3	60	35	5	10.6	89.4
B−38	1–4	94	3	3	60	35	5	6.5	93.5
B−46	1–4	92	4	4	20	70	10	5.3	94.7

THE CHEMISTRY, OPTICS, AND GENESIS OF THE ALKALI-AMPHIBOLES

By

Akiho MIYASHIRO

Abstract

The alkali-amphiboles are divided into the groups of riebeckite-glaucophane, of arfvedsonite, of katophorite and of soda-tremolite on the basis of the degrees of the (Na, K) $R'' \leftarrow\rightarrow R'''$ and (Na, K)$Al \leftarrow\rightarrow Si$ substitutions, where R''' and R'' represent trivalent and divalent atoms in 6-coordination respectively (Fig. 1). The first three groups are in serial relation, being governed by the substitution $R'''Si \leftarrow\rightarrow CaR''Al$. This series is called the riebeckite-arfvedsonite-katophorite series.

Each group is subdivided on the basis of the $Al \leftarrow\rightarrow Fe'''$ substitution in R''' and the $Mg \leftarrow\rightarrow Fe''$ substitution in R''. The idealized formulas of main subdivisions are as follows:

Riebeckite-glaucophane group	
Riebeckite	$Na_2Fe_3''Fe_2'''Si_8O_{22}(OH)_2$
Magnesioriebeckite	$Na_2Mg_3Fe_2'''Si_8O_{22}(OH)_2$
Glaucophane proper	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
Arfvedsonite group	
Arfvedsonite	$Na_2Ca_{0.5}Fe_{3.5}''Fe_{1.5}'''Si_{7.5}Al_{0.5}O_{22}(OH)_2$
Magnesioarfvedsonite	$Na_2Ca_{0.5}Mg_{3.5}Fe_{1.5}'''Si_{7.5}Al_{0.5}O_{22}(OH)_2$
Katophorite group	
Katophorite	$Na_2CaFe_4''Fe'''Si_7AlO_{22}(OH)_2$
Magnesiokatophorite	$Na_2CaMg_4Fe'''Si_7AlO_{22}(OH)_2$
Soda-tremolite group	
Soda-tremolite	$Na_2CaMg_5Si_8O_{22}(OH)_2$

The relations of the chemical compositions to the optical properties and to the modes of occurrence are examined in detail. In the riebeckite-arfvedsonite-katophorite series, the formation temperature increases generally with the increase of $CaR''Al$. The alkali-amphiboles are a fairly good temperature indicator. It is interesting that the high pressure member (glaucophane) is high in 6-coordinated Al, whereas the high temperature member (katophorite group) is high in 4-coordiated Al.

I. Introduction

In this paper I intend to give a critical compilation and review of the existing data on the chemical compositions, substitution relations, optical properties and modes of occurrence of the alkali-amphiboles. The main purpose of this study is to have a better grasp of their petrological properties in relation to the problems of glaucophane-schists and alkalic igneous rocks.

The most remarkable progress in the systematic treatment of amphibole in recent years was made by HALLIMOND (1943). He deviced a useful method of graphical representation of the composition relations of the calciferous amphiboles, and thereby opened up a new way in the study of amphibole in general. Then, SUNDIUS (1946) made another important contribution in the systematic study of calciferous as well as alkali amphiboles. I am greatly indebted to these works.

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The alkali-amphiboles are generally high in alkali and low in Ca content. Their CaO contents by weight are lower than 6% except in some katophorites and soda-tremolites. Amphiboles higher in Ca and generally lower in alkali content, such as barkevikite and hastingsite, are not treated in this paper, because they belong to the family of calciferous amphiboles and not to that of alkali-amphiboles. The CaO content of the calciferous amphiboles are usually higher than 9%.

In this paper, the boundaries between subdivisions of the alkali-amphiboles are determined on the principle that they should conform, as far as possible, with the general current usage of the names for the subdivions, and also with differences in their modes of occurrence. It is important from petrological point of view to take the modes of occurrence into consideration.

Unfortunately the identification of alkali-amphiboles and the description of their optical properties in the literature are erroneous in many cases. Therefore the literature should be examined with great care. The chemical analyses that can not be reconciled with the structural formula derived from the X-ray studies are mostly rejected in the present study.

Eckermannite (Adamson, 1944; Sundius, 1945b) and holmquistite (Osann, 1913; Sundius, 1947) are not treated in this paper, because they are very different from the other alkali-amphiboles in their richness in Li. The Li must have some effects on the optical properties as well as on the stability.

II. Graphical Representation of the Main Substitutions

The X-ray studies of Warren (1929, 1930) have established the chemical formula of tremolite as $Ca_2Mg_5Si_8O_{22}(OH)_2$, and have shown that the formulas of the other amphiboles can be derived by isomorphous substitutions from the tremolite formula. The Ca atoms of tremolite may be replaced by Na and K. The Mg atoms may be replaced by Mn, Fe″, Al and Fe‴. The Si atoms may be replaced partly by Al. At most one more (Na, K) atom can enter the vacant space of the structure. Thus we come to the general formula of the alkali-amphiboles as follows:

$$(Na, K, Ca)_{2-3}(R'', R''')_5(Si, Al)_8O_{22}(OH)_2$$

The (Na, K, Ca) atoms are in 8- and 12-coordinated positions, (R″, R‴) atoms are in 6-coordinated ones and the (Si, Al) atoms are in 4-coordinated ones.

The substitutions of $R'' \leftrightarrow R'''$ and of $Si \leftrightarrow Al$ are between atoms of different valencies. Then some additional substitutions must accompany them in order to maintain electrical neutrality. If we neglect the sustitution among Na, K and Ca, the electrical neutrality is maintained by intoducing (Na, K) atoms into the vacant spaces. Thus, the compositional variation of the alkali-amphiboles may be represented mainly by the following two kinds of substitution: (Na, K) $R'' \leftrightarrow R'''$ and (Na, K) $Al \leftrightarrow Si$. The sustitution $R''Si \leftrightarrow R'''Al$ may be regarded as a combination of these two.

Indeed, the Ca and K contents of the alkali-amphiboles are generally low in comparison to the Na content, and so we can neglect the substitution among Na, K and Ca as a first approximation. Consequently the main compositional variation of the alkali-amphiboles can be graphically shown by a rectangular diagram having the degrees of the above two subtitutions as coordinates. Such a diagram is shown in Fig. 1, in which the abscissa represents the amount of R‴ and the ordinate represents that of Si. Special attention should be paid to the fact that symbols R‴ and R″ in this paper do not represent all the amounts of trivalent and divalent

atoms respectively but represent only the trivalent and divalent atoms which are in 6-coordinated positions.

If the Ca content is zero, only the area having $Na_2R''_3R'''_2Si_8O_{22}(OH)_2$, $Na_3R''_4R'''Si_8O_{22}(OH)_2$, $Na_3R''_2R'''_3Si_6Al_2O_{22}(OH)_2$, and $Na_2R''_2R'''_3Si_7AlO_{22}(OH)_2$ at its four corners is in harmony with the condition that Na+K=2−3. This area is indicated by broken lines in Fig. 1. However, actually the Ca content is not always negligible, and we will see that points fall not only on the area but also widely to the left.

III. Four Groups in the Alkali-Amphiboles

A number of reliable chemical analyses of the alkali-amphiboles were collected from the literature. The H_2O content in many of these analyses is not reliable. Moreover, H_2O_+ and H_2O_- are not always separated from each other. Then, all the analyses were calcualated into the chemical formula on the basis of O=2300, excluding the oxygen in H_2O. This procedure is equivalent to the assumption of (OH, F)=200. (The basis of O=2300 was adopted instead of O=23.00, only because it simplifies the printing of the table concerned by avoiding decimal points.) The results of the calculation are shown in Table 1. The optical properties of the analysed amphiboles, so far as given in the original descriptions, are shown in Table 2. The analysis numbers are common to both tables.

In Table 1, the Al is divided into those in 4-coordination (Al^{IV}) and in 6-coordination (Al^{VI}), and the water content is shown as H_2O in molecular ratio on the same basis. When H_2O_+ and H_2O_- are distinguished in the analysis, only the H_2O_+ is taken into calculation, and the result is indicated by figures with sign+ before. (For example, see "+100" in No. 1.) When H_2O_+ and H_2O_- are not distinguished, the figures concerned indicate the total H_2O. (For example, see "97" in No. 6.) The bar— means that the component concerned was not determined.

The amphiboles of Table 1 are plotted in Fig. 1, which have R''' and Si as the coordinates. Since symbols R''' and R'' in this paper represent the trivalent and divalent atoms respectively in 6-coordination, $R'''+R''$ should be equal to 500 in the idealized compositions, and is either equal or close to 500 in the reliable actual compositions. The Ti atoms in 6-coordination are included in the R''' group for the sake of convenience, though they are probably tetravalent. (This procedure will be permissible as the Ti content is usually small.)

The actual procedure of calculating R''' and R'' is as follows: Si is smaller than 800 in most cases, and so Al is allotted so that Si+Al=800. These Si and Al atoms represent the cations forming (Si, Al)−O tetrahedra. Rarely the Si and Al atoms are too small in amount to fulfill the condition Si+Al=800. In such cases Ti is added to fulfill the condition Si+Al+Ti=800. When the total amount of Si, Al and Ti joined is still smaller than 800, the want is left as it is. The remaining Al and Ti are regarded as being situated in 6-coordinated positions, together with Fe''', Fe'', Mn, and Mg. Then R''' and R'' are calculated from them as $R''' = Al+Ti+Fe'''$ and $R''=Fe''+Mn+Mg$. In a few cases Si is slightly over 800, and all the Si atoms are treated as forming Si−O tetrahedra.

Some part of Mn may be present in 8-coordinated positions, together with Ca, K and Na. But this possibility is disregarded for the present. This disregard will not cause any serious error, as the Mn content is usually very small.

In Fig. 1, we can notice a close relationship between the chemical compositions and modes of occurrence of the alkali-amphiboles. The amphiboles from igneous

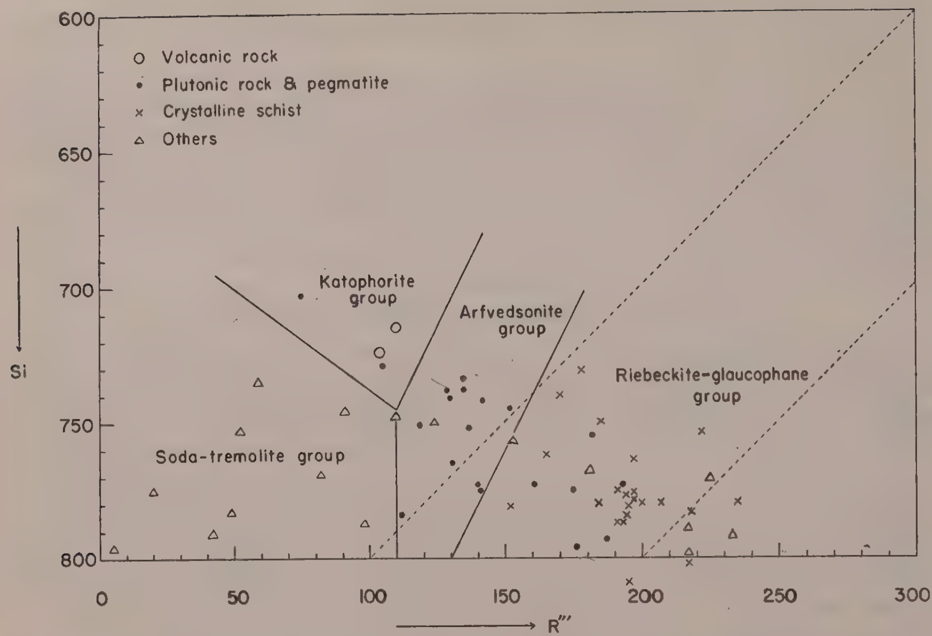

Fig. 1. The (Na, K) R''$\leftarrow\rightarrow$R''' and (Na, K) Al$\leftarrow\rightarrow$Si substitutions in the alkali-amphiboles. The symbols represent the host rocks. "Others" represented by triangles include metamorphosed ironstone and limestone and hydrothermal products.

rocks fall on the upper central part of the composition field, while those from crystalline schists and other metamorphic rocks fall on the lower part at the right and left ends of the compostition field. In some intermediate parts, amphiboles from both igneous rocks and crystalline schists appear intermingled.

As shown in Fig. 1, the alkali-amphiboles are divided into four groups: riebeckite-glaucophane, arfvedsonite, katophorite and soda-tremolite groups. Each boundary between the fields of these groups is a straight line passing through two points as follows:

Between the fields of the riebeckite-glaucophane and arfvedsonite groups: (R''' =130, Si=800) and (R'''=180, Si=700).

Between the fields of the arfvedsonite and katophorite groups: (R'''=110, Si =745) and (R'''=140, Si=685).

Between the fields of the katophorite and soda-tremolite groups: (R'''=110, Si =745) and (R'''=50, Si=700).

Between the fields of the arfvedsonite and soda-tremolite groups: (R'''=110, Si =745) and (R'''=110, Si=800).

These boundaries are in harmony with the current usage of the names of the four groups.

Each group will be subdivided later according to the Fe'''/R''' and Fe''/R'' ratios. Table 1 shows mineral names that are given systematically to the subdivisions in this paper. The definitions of these names will be explaind later. In many cases these names agree to those given in the original descriptions. When they differ, the systematic names adopted in this paper are followed by the names of the original descriptions in brackets.

IV. Ca Contents and Group Formulas

The Ca contents of the alkali-amphiboles excluding soda-tremolite are shown in Fig. 2. It is clear that the Ca content increases rather regularly with the decrease of R‴. Thus, the Ca contents are usually small in the riebeckite-glaucophane

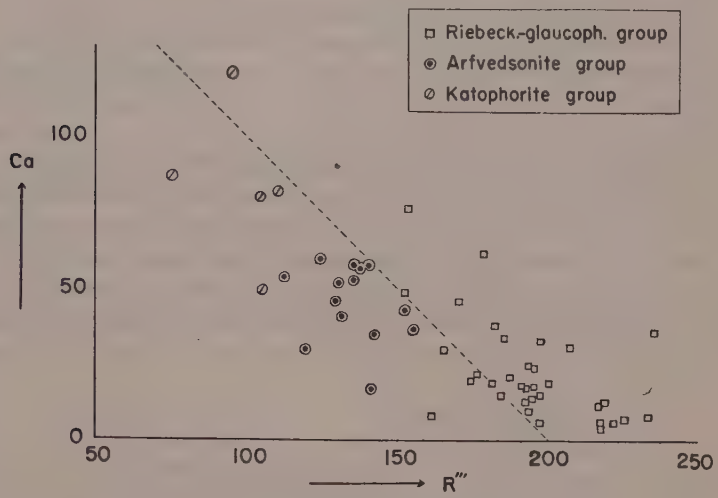

Fig. 2. The Ca contents of alkali amphiboles (excluding soda-tremolite).

group, but are larger in the arfvedsonite and katophorite groups. The idealized compositions of arfvedsonite and katophorite should have Ca contents of about 50 and 100 respectively.

Thus, from Figs. 1 and 2, we obtain the idealized formulas which follow:

Riebeckite-glaucophane group	$Na_2R_3''R_2'''Si_8O_{22}(OH)_2$
Arfvedsonite group	$Na_2Ca_{0.5}R_{3.5}''R_{1.5}'''Si_{7.5}Al_{0.5}O_{22}(OH)_2$
Katophrite group	$Na_2CaR_4''R'''Si_7AlO_{22}(OH)_2$

The compositional variation between the three groups is expressed by the substitution $R'''Si \leftarrow\rightarrow CaR''Al$. Then the riebeckite-glaucophane, arfvedsonite, and katophorite groups are in serial relation.

The formula of the riebeckite-glaucophane group given above is practically the same as those given by Kunitz (1930) and Sundius (1946), whereas that of the arfvedsonite group is different. The formulas of arfvedsonite given in most, if not all, of the literature are wrong. Only the above formula enables us to correlate the compositions with their optical properties and modes of occurrence.

The soda-tremolite group has the following idealized formula;

$$Na_2CaR''_5Si_8O_{22}(OH)_2$$

This formula can be derived from the tremolite formula $Ca_2Mg_5Si_8O_{22}(OH)_2$ by the substitution $Ca \leftarrow\rightarrow Na_2$.

V. Riebeckite-Glaucophane Group

1. General statement

Fig. 3 shows the Fe'''/R''' and Fe''/R'' ratios of amphiboles of the riebeckite-glaucophane group.

$Fe'''/R'''=Fe'''/(Al+Ti+Fe''')$ in 6-coordination.

$Fe''/R''=Fe''/(Mg+Mn+Fe'')$ in 6-coordination.

As the Ti and Mn contents are usually very small, these ratios represent practically the degrees of the $Al \longleftrightarrow Fe'''$ substitution in R''' and the $Mg \longleftrightarrow Fe''$ substitution in R'' respectively.

The amphiboles with Fe'''/R''' ratios lower than 0.7 occur characteristically in the so-called glaucophane-schist group of metamorphic rocks, whereas those with Fe'''/R''' ratios higher than 0.7 occur not only in such rocks but also in other metamorphic as well as alkalic igneous rocks. Then, it is in harmony with petrographical custom and convenience to call the amphiboles with the Fe'''/R''' ratios lower than 0.7 "*glaucophane*" or "*glaucophane in a broad sense*".

As shown in Fig. 3B, the members rich in Al and Mg ($Fe'''/R'''<0.3$, $Fe''/R''<0.5$) will be called *glaucophane proper*, and their ferrous analogues will be

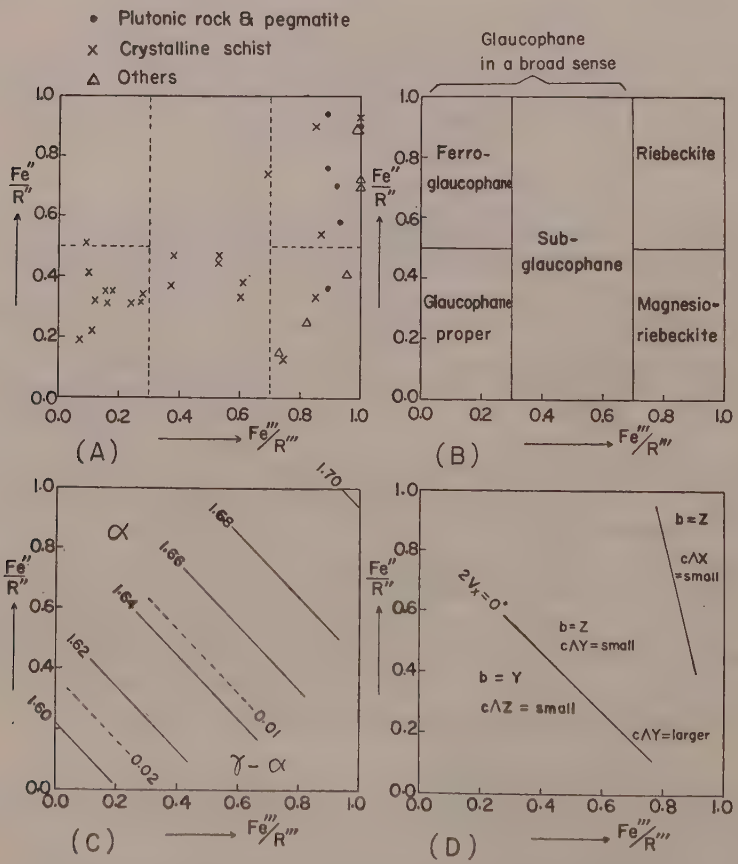

Fig. 3. The Fe'''/R''' and Fe''/R'' ratios in amphiboles of the riebeckite-glaucophane group. (A) compositions, (B) nomenclature, (C) refractive indices, (D) optic orientation.

called *ferroglaucophane*. The members with intermediate values of Fe'''/R''' ratio (0.3–0.7) will be called *subglaucophane*.

The members rich in Fe''' and Fe'' (Fe'''/R'''>0.7, Fe''/R''>0.5) will be called *riebeckite*, whereas their magnesium analogues will be called *magnesioriebeckite*.

The idealized formulas of these members are as follows:

Riebeckite	$Na_2Fe_3''Fe_2'''Si_8O_{22}(OH)_2$
Magnesioriebeckite	$Na_2Mg_3Fe_2'''Si_8O_{22}(OH)_2$
Subglaucophane	$Na_2Mg_{1.5}Fe_{1.5}''AlFe'''Si_8O_{22}(OH)_2$
Glaucophane proper	$Na_2Mg_3Al_2Si_8O_{22}(OH)_2$
Ferroglaucophane	$Na_2Fe_3''Al_2Si_8O_{22}(OH)_2$

Kunitz (1930) has claimed that there is a continuous series of solid solution between glaucophane and tremolite-actinolite. However, this statement is not justified as was already discussed by Sundius (1946, p. 11). (What was called tremolite-glaucophane by Polovinkina (1924) is actually a soda-tremolite.)

2. Optical properties

C and D of Fig. 3 show the relation between the chemical compositions and optical properties in this group. The refractive indices increase from the corner of glaucophane proper to that of riebeckite, that is, with the increase of Fe''' and Fe''. So far as the refractive indices are concerned, the riebeckite-glaucophane group may be regarded as a pseudo-binary system corresponding to the diagonal from glaucophane proper to riebeckite, as is shown in Fig. 4. As regards the other optical properties such as optical orientation, such a treatment may not be justified.

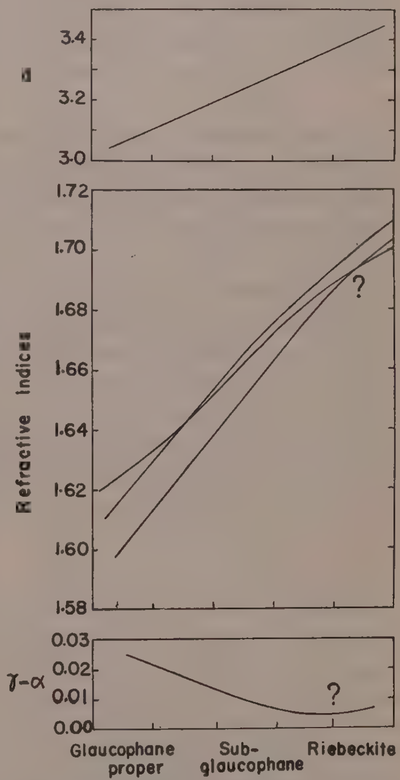

Fig. 4. Refractive indices and density in the pseudo-binary series of glaucophane proper, subglaucophane and riebeckite.

In glaucophane near the MgAl corner of the diagram Fig. 3D, b=Y, $c\wedge$Z=small (4°–15°) and $2V_x$=medium (ca. 50°) to small. The optic axial plane is parallel to (010). Hence such glaucophane may be called *parallel-symmetric* one. With the increase of Fe''' and Fe'', the optical angle becomes smaller down to zero. With further increase of Fe''' and Fe'', it becomes larger again in the optic axial plane normal to (010). Thus, b=Z and $c\wedge$Y=small (2°–15°). Amphiboles having such an optical orientation (i. e. normal-symmetric glaucophanes) have been usually called *crossite*. (This name will be discussed later.) Tschopp (1923), Horikosi (1936) and de Roever (1947) have observed practically uniaxial amphiboles on the boundary between

parallel-symmetric glaucophane and crossite.*

In riebeckite near the Fe''Fe''' corner of the diagram, b=Z and $c\wedge$X=small (0°–5°) The literature shows confusions and contradictions in the optical description of riebeckite, mainly as a result of very strong absorption. Some riebeckites were reported to be optically positive and others optically negative. Some riebeckites do not show complete extinction between crossed nicols even with monochromatic light (e. g. MIYASHIRO and MIYASHIRO, 1956).

The optical properties of the transitional minerals between crossite and riebeckite with $c\wedge$X=small are not clear. Fig. 4 shows a possible (if not probable) interpretation for the transitional state that the mineral becomes uniaxial positive on the boundary.

The pleochroism is as follows. In parallel-symmetric glaucophane, X=pale yellow, Y=bluish violet, and Z=blue with X<Z<Y. In crossite, X=pale yellow, Y=blue, and Z=violet with X<Y<Z. In riebeckite with $c\wedge$X=small, X=greenish blue, Y=light brownish yellow, and Z=dark bluish grey with Y<X≦Z, according to VENDL (1924).

In the members of the group near the diagonal from glaucophane proper to riebeckite, the extinction angle is smaller than 15°, as mentioned above. However, in magnesioriebeckites, near the MgFe''' corner of the diagram, the extinction angle is much larger. Thus, for example, b=Y and $c\wedge$Z= about 30°–35° in some magnesioriebeckites with very low Fe''/R'' ratios, and b=Z and $c\wedge$Y= about 28° in others. The optical angle about X is small (0°–50°). The most remarkable feature of such magnesioriebeckites is that two of the principal axes of the absorption ellipsoid show a large departure from the axes of the indicatrix. One of the absorption axes is parallel to b, another is parctically parallel to c and the remaining is practically normal to both b and c.**

Amphiboles having such optical properties were called *torendrikite* by certain writers. (Some of torendrikites belong to magnesioriebeckite and others to magnesioarfvedsonite in composition. This name will be discussed in the next chapter.)

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* The descriptions of the axial dispersion of glaucophanes in the literature show marked contradictions to one another. According to recent observations of Shohei BANNO (personal communication), parallel-symmetric glaucophanes with optic angles larger than 30° show weak axial dispersion of $\rho<\upsilon$, but parallel-symmetric glaucophanes with optic angles smaller than 30° show too weak axial dispersion to be determined. Probably the axial dispersion of parallel-symmetric glaucophane becomes zero when the optic angle is about 10°. Normal-symmetric glaucophanes (crossites) with optic angles larger than 10° show strong axial dispersion of $\rho\ll\upsilon$.

** The following optical properties were observed in a magnesioriebeckite from a crystalline schist of Bizan in Sikoku (MIYASHIRO and IWASAKI, 1957), though the mineral is not included in Table 1, because it was analyzed after the completion of the table. b=Z; $c\wedge$Y=28° for yellow light, 31° for green and 35° for blue; 2V over X=43° for yellow light and 51° for green. α=1.660 and γ=1.670 for yellow light. Owing to very strong dispersion, the (010) section does not show extinction for white light, but shows complete extinction for monochromatic light. The pleochroism is as follows: parallel to b=purple, practically parallel to c=blue, and practically normal to both b and c=very pale yellow (nearly colorless). Absorption: parallel to b= parallel to c> normal to both b and c. Its composition is as follows: Si=780, Al(IV)=20, Al(VI)=55, Ti=3, Fe'''=136, Fe''=41, Mn=15, Mg=250, Ca=29, Na=152, K=7, H_2O=+92 and F=n. d., all on the anhydrous basis of O=2300. Its host-rock is a garnet-aegirine-amphibole-muscovite-quartz-schist from Bizan in the city of Tokusima, Sikoku, and belongs to the Sanbagawa schists.

3. Modes of occurrence

Riebeckite occurs in alkalic igneous rocks as well as in crystalline schists and metamorphosed ironstones. The alkalic igneous rocks concerned include granites, quartz-syenites, syenites and nepheline-syenites. However, metamorphic riebeckites have generally larger R‴ values than igneous ones, as shown later (Fig. 7). SUZUKI (1939) described a riebeckitic amphibole (called crocidolite) with unusually high refractive indices (β=about 1.71; $c \wedge X=0°-2°$) from a low-grade schist of Hokkaido. Probably it is also a typical riebeckite with a very high R‴ value.

Magnesioriebeckite occurs rarely in alkalic igneous rocks, but more commonly in crystalline schists and other metamorphosed rocks.

Subglaucophane and glaucophane proper occur only in crystalline schists and associated rocks. Ferroglaucophane with relatively low Fe″/R″ ratios occurs in crystalline schists, but that with relatively high Fe″/R″ ratios has not been found in any rocks.

4. Conditions of formation

Riebeckite and magnesioriebeckite have a large excess of alkalies over the alkalies/alumina ratio of alkali-feldspars. Then, their formation should be promoted by richness in alkalies, especially by the presence of excess alkalies in the rocks. However, most rocks in the earth's crust have no excess of alkalies. The excess of alkalies can be present generally only in two cases: (1) in alkalic igneous rocks and their metamorphic derivatives, and (2) in rocks whose compositions were markedly modified by alkali-metasomatism (or metamorphic differentiation). Therefore the occurrence of riebeckite and magnesioriebeckite is very limited. So far as such chemical conditions are fulfilled, riebeckite and magnesioriebeckite probably form under both high and low pressures, at generally low temperatures.

On the other hand, Fe‴-free glaucophane does not require any excess of alkalies for its formation. This fact will be understood from the following examples of chemical equations:

$$\underset{\text{glaucophane}}{2H_2Na_2Mg_3Al_2Si_8O_{24}}+2H_2O=\underset{\text{albite}}{4NaAlSi_3O_8}+\underset{\text{antigorite molecule (in chlorite)}}{H_8Mg_6Si_4O_{18}}$$

$$\underset{\text{glaucophane}}{5H_2Na_2Mg_3Al_2Si_8O_{24}}+\underset{\text{lawsonite}}{2CaAl_2Si_2O_8\cdot 2H_2O}$$

$$=\underset{\text{albite}}{10NaAlSi_3O_8}+\underset{\text{chlorite}}{2H_8Mg_5Al_2Si_3O_{18}}+\underset{\text{tremolite}}{H_2Ca_2Mg_5Si_8O_{24}}$$

The alkalies of Fe‴-free glaucophane can be supplied from albite. Therefore the chemical condition for the formation of Fe‴-free glaucophane can be fulfilled generally easily. Thus, Fe‴-free glaucophane should form easily only if some physical conditions are fulfilled. The glaucophane-bearing sides of the above equations have smaller solid volumes than the other sides, and we may safely consider that the essential factor of physical condition for the formation of Fe‴-free glaucophane is high solid pressures combined with low temperatures, as is discussed in another paper (MIYASHIRO and BANNO, 1958).

Glaucophane proper and ferroglaucophane, being poor in Fe‴, would resemble the Fe‴-free glaucophane in the condition of formation. As subglaucophane is intermediate in chemical composition between Fe‴-free glaucophane on the one hand and riebeckite and magnesioriebeckite on the other, its formation must be effectively controlled by both physical conditions (high pressure and low temperature) and

chemical ones (including the presence of excess alkalies).

The composition and stability of the members of the riebeckite-glaucophane group may be schematically represented by the diagram of Fig. 5. Under very high

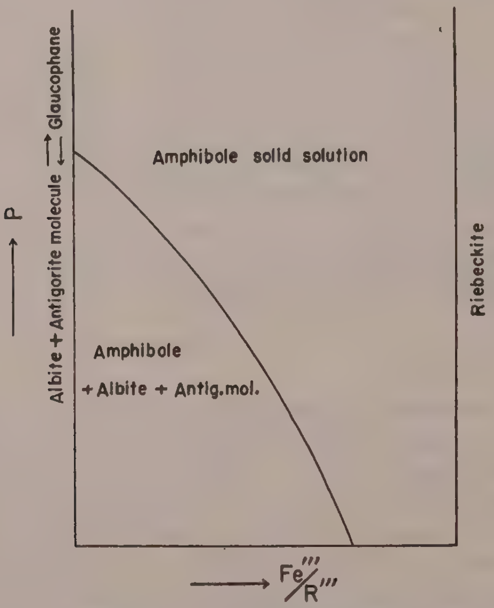

Fig. 5. The composition and stability in regard to solid pressure of the amphiboles of the riebeckite-glaucophane group.

pressure and low temperature, any member of the riebeckite-glaucophane group may form, its composition depending upon that of the host-rock. At lower pressure and /or higher temperature, the possible composition field of the amphibole becomes smaller, and glaucophane proper and ferroglaucophane become unstable. At still lower pressure and/or higher temperature, the possible composition field becomes confined to the area of riebeckite and magnesioriebeckite

The problem treated in this section has been discussed in greater detail in another paper (MIYASHIRO and BANNO, 1958).

5. Names and varieties

Riebeckite was first recognized to be a member of the amphiboles by SAUER in 1885 and was named in honor of Emil RIEBECK. *Glaucophane* was first described and named by HAUSMANN in 1845 from the island of Syra in the Cyclades without knowing that it belongs to the amphiboles. The name came from the blue color in Greek (HINTZE, 1897).

Some writers restricted the use of the name glaucophane only to the parallel-symmetric variety. However, such a nomenclature would lead to an unfortunate confusion.

The name *crossite* was proposed by PALACHE (1894) in honor of the geologist W. CROSS for an amphibole that generally resemble glaucophane and riebeckite but was considered to have distinctive optical properties. He stated that the optic axial plane of the crossite was parallel to (010) with b=Y, and the X axis is near to c. However, this statement was erroneous. SWITZER (1951) reexamined the original specimen of PALACHE, and noticed that actually the crossite has the optic axial

plane perpendicular to (010) with b=Z and $c \wedge$Y=2°.

Some writers regarded crossite as having been defined by the composition which is intermediate between those of glaucophane proper and of riebeckite (e. g., HOLGATE, 1951). Other writers considered that crossite is an alkali-amphibole with the optic axial plane normal to (010) with b=Z and $c \wedge$Y=small (e. g., DE ROEVER, 1947). These two definitions, chemical and optical, do not agree to each other. (For example, some minerals having intermediate compositions show b=Y.) Probably the optical definition has been adopted more generally. I believe that such an optically defined name is covenient for us in petrographical works. Such optically defined crossite belongs in chemical composition to subglaucophane in most cases, and to riebeckite and magnesioriebeckite in rare cases.

Osannite (HLAWATSCH, 1906) is a variety of riebeckite.

Ternovskite (POLOVINKINA, 1924) belongs to magnesioriebeckite.

Crocidolite is fibrous amphibole or asbestos, having riebeckite or magnesioriebeckite composition. Usually it occurs in ironstones, probably slightly metamorphosed at very low temperatures after deposition.

The name *gastaldite* was proposed for a glaucophane-like amphibole from St. Marcel by STRUEVER in 1875 (refer to MILCH, 1907). The original analysis shows an unusually high R''' value (R'''=300). A later analysis of a similar mineral from the same locality by ZAMBONINI (1906) gave an ordinary composition of glaucophane proper. It seems that the original analysis was wrong.

Torendrikite (LACROIX, 1920) will be discussed in the next chapter.

VI. Arfvedsonite Group

1. General statement

Fig. 6A shows the Fe'''/R''' and Fe''/R'' ratios of amphiboles of the arfvedsonite group. The Fe'''/R''' ratios are larger than 0.7 in these amphiboles with only one exception.

The main substitution in this group is Mg←→Fe. The Fe''-rich membere (Fe''/R''>0.5) are called *arfvedsonite*. The Mg-rich members (Fe''/R''<0.5) will be called *magnesioarfvedsonite*.

The idealized formulas of these members are as follows:

Arfvedsonite	$Na_2Ca_{0.5}Fe_{3.5}''Fe_{1.5}'''Si_{7.5}Al_{0.5}O_{22}(OH)_2$
Magnesioarfvedsonite	$Na_2Ca_{0.5}Mg_{3.5}Fe_{1.5}'''Si_{7.5}Al_{0.5}O_{22}(OH)_2$

2. Optical properties

In arfvedsonite, b=Z, $c \wedge$X=small to medium (0°–30°), $\alpha=1.67-1.70$, $\gamma=1.68-1.71$ and $\gamma-\alpha=0.005-0.012$ The determination of optical angle and orientation is very difficult owing to strong absorption. The literature shows confusions in the description of pleochroism.

One of the principal axes of the absorption ellipsoid is parallel to b, and hence is parallel to Z, but the others show a departure from the axes of the indicatrix, as in the case of magnesioriebeckite. This fact was described in detail by SHODA (1956) on a variety of arfvedsonite (called heikolite). According to him, one of the absorption axes is parctically parallel to c, and the remaining is practically parallel to both b and c. The pleochroism is as follows: parallel to b=deep yellowish green; practically parallel to c=deep bluish green; and practically normal to both b and c=yellowish brown. Parallel to c> parallel to b> normal to both b and c.

Arfvedsonite resembles riebeckite in optical properties except the extinction angle ($c \wedge X$). At least some arfvedsonites do not show complete extinction between crossed nicols even with monochromatic light. The phenomenon was studied in detail by several investigators such as ESKOLA and SAHLSTEIN (1931b), IWAO (1939), SHODA (1954), SAHAMA (1956) and SHODA (1956).

In magnesioarfvedsonite, $b=Z$, $c \wedge X$=large (18°–50°) with very strong dispersion, $\alpha=1.65-1.66$, $\gamma=1.66-1.67$, and $\gamma-\alpha=0.01-0.02$. The principal axes of the absorption ellipsoid in magnesioarfvedsonite also show a large departure from those of indicatrix. This feature was described by several writers. DENAEYER (1924) gives the pleochroism of a variety of the mineral (called torendrikite) as follows: parallel to b=greyish violet; practically parallel to c=bluish green; and practically normal to both b and c=light greenish yellow. Parallel to $b>$ parallel to $c>$ normal to both b and c.

Probably, in magnesioarfvedsonites with very low Fe''/R'' ratios, $b=Y$ and the extinction angle is very large.

3. Modes of occurrence

Arfvedsonite occurs only in alkalic igneous rocks—commonly in nepheline-syenites and rarely in syenites and quartz-bearing rocks.

Magnesioarfvedsonite occurs in alkalic igneous rocks, including syenitic and nepheline-syenitic rocks. LARSEN (1942) described a magnesioarfvedsonite from a hydrothermal product associated with alkalic igneous rocks of Iron Hill, Colorado, under the unfortunate name glaucophane.

4. Names and Varieties

Arfvedsonite was first described by BROOKE in 1823 from Greenland and was named in honor of the Swedish chemist J. A. ARFVEDSON (HINTZE, 1897).

Heikolite (KINOSAKI, 1935) is a variety of arfvedsonite with a composition near the boundary to riebeckite.

The name *torendrikite* was proposed by LACROIX (1920) for an amphibole from alkalic syenite in Madagascar. The amphibole belongs to magnesioarfvedsonite in composition. Later, DENAEYER (1924), DE ROEVER (1947), etc. called optically resembling amphiboles torendrikite without chemical analysis. The diagnostic features of these amphiboles were a large departure of the absorption axes from the axes of the indicatrix, together with relatively large extinction angle and low refractive indices.

The amphibole of DE ROEVER was from a metamorphic rock of the glaucophane-schist group. MIYASHIRO and IWASAKI (1957) described an amphibole, whose optical properties are practically identical to those of the DE ROEVER's, from a crystalline schist of Bizan. It belongs to magnesioriebeckite in composition. Thus, it is reasonable to consider that the name torendrikite represents a series of alkali-amphibole characterized by certain optical properties, as mentioned above, and that in chemical composition torendrikite ranges from magnesioarfvedsonite to magnesioriebeckite.

MOROZEWICZ (1925, 1930) described a series of alkali-amphiboles from syenitic pegmatites of Mariupol in Ukraine under the name *fluotaramite*. Most of the fluotaramites belong to magnesioarfvedsonite and the remaining belong to magnesioriebeckite.

VII. Katophorite Group

1. General statement

The name katophorite was proposed by BROEGGER (1894) for an amphibole characterized by deep reddish brown color and a fairly large extinction angle. The oldest chemical analysis of such an amphibole had been made by OSANN (1888) before. Some writers spelled the name *katoforite*, *kataphorite*, and *cataphorite*.

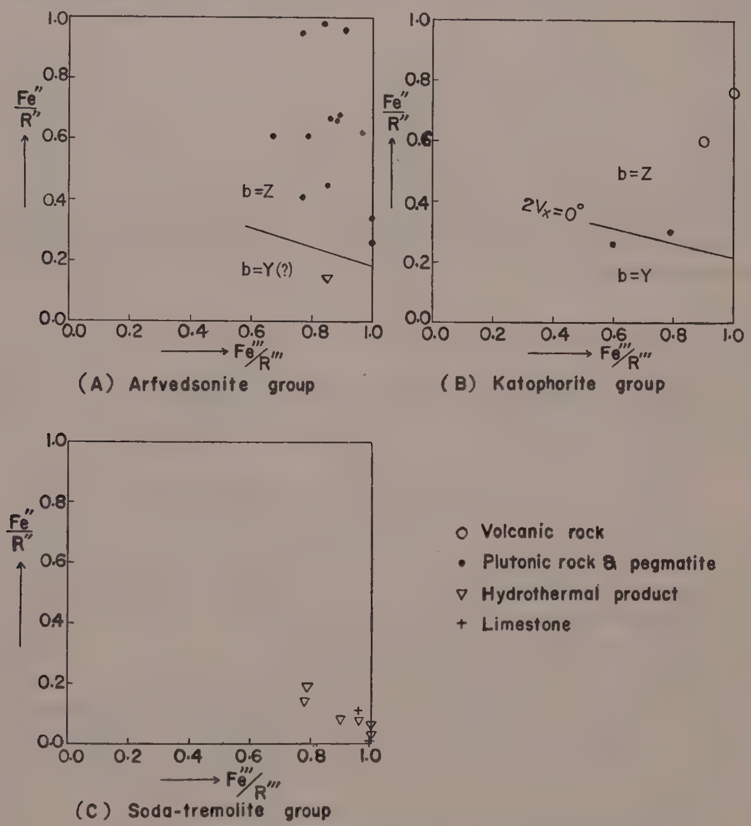

Fig. 6. The Fe′′′/R′′′ and Fe′′/R′′ ratios in amphiboles of the arfvedsonite, katophorite, and soda-tremolite groups.

Fig. 6B shows the Fe′′′/R′′′ and Fe′′/R′′ ratios of amphiboles of the katophorite group. The Fe′′′/R′′′ ratios are large in these amphiboles, similarly as in the arfvedsonite group.

The main substitution in this group is Mg←→Fe′′. The Fe′′-rich members (Fe′′/R′′>0.5) will be called simply *katophorite* and the Mg-rich members (Fe′′/R′′<0.5) will be called *magnesiokatophorite*.

The idealized formulas of these members are as follows:

Katophorite	$Na_2CaFe''_4Fe'''Si_7AlO_{22}(OH)_2$
Magnesiokatophorite	$Na_2CaMg_4Fe'''Si_7AlO_{22}(OH)_2$

2. Optical properties

In katophorites and some magnesiokatophorites, b=Z and $c\wedge$X=36°–70°, with

$\rho>\upsilon$, whereas in other magnesiokatophorites $b=Y$ and $c\wedge X=52°–56°$ ($c\wedge Z=34°–38°$) with $\rho<\upsilon$. At the boundary between the two cases where $b=Z$ and $b=Y$, the mineral is to be uniaxial negative. The optical angle over X is usually small (0°–52°) in this group.

The α index ranges from 1.639 to 1.681, and the birefringence ($\gamma-\alpha$) ranges from 0.007 to 0.021 in the literature.

In crystals with $b=Z$, X=pale brown, Y=greenish brown, and Z=deep purple-reddish brown, whereas in crystals with $b=Y$, X=yellow, Y=deep brown, and Z=greenish brown.

3. Modes of occurrence

Katophorite occurs in alkalic igneous rocks, including theralite, shonkinite, trachyte and sanidinite inclusions in trachyte. These rocks belong to either volcanic or associated plutonic masses. Katophorite is associated with sanidine in most cases.

I have repeatedly stated that the crystallization temperature of alkalic igneous rocks differs in different complexes (MIYASHIRO, 1951; MIYASHIRO and MIYASHIRO, 1956). Katophorite appears to be confined to the higher-temperature group of alkalic rocks.

4. Variety

The name *anophorite* (FREUDENBERG, 1910) was proposed for a magnesiokatophorite in shonkinite of Katzenbuckel in Odenwald, Germany.*

VIII. Riebeckite-Arfvedsonite-Katophorite Series

We have seen that the riebeckite-glaucophane, arfvedsonite, and katophorite groups are in serial relation. The compositional differences between the groups are governed by the substitution R'''Si←→CaR''Al. This series will be called the *riebeckite-arfvedsonite-katophorite series* in this paper.

It is interesting that with the increase of CaR''Al the formation temperature of the minerals of this series tends to become higher. This relation is clearly shown in Fig. 7. The fields of igneous and metamorphic amphiboles are separated nearly perfectly from each other in this figure. The igneous field represents higher temperature than the metamorphic one. Thus, probably the formation temperature generally increases from the lower right part to the upper left. Then it is significant that katophorites from volcanic rocks, probably having crystallized at the highest temperatures among the alkali-amphiboles, fall on the upper left end of the whole composition field. The kind of alkali-amphiboles formed should be a useful temperature indicator in petrology.

* According to FREUDENBERG (1910), the Katzenbuckel "anophorite" (No. 51 in Tables 1–2) has the following properties: the extinction angle=20°–27°, the optic plane normal to (010), 2E=44°20′, and $\rho>\upsilon$. In order to make the optic orientation clearer, I examined "anophorite" in the Katzenbuckel shonkinite, composed of augite ($c\wedge Z=45°$) with an aegirine rim ($c\wedge X=0°$), nepheline, sanidine (2V=10°), olivine, anophorite, apatite and opaque minerals. The anophorite has the following properties: $c\wedge Y=30°$ for yellow light and 28° for green light, $b=Z$ with the optic plane normal to (010), 2V over X=52° for yellow light and 40° for green light, $\rho>\upsilon$, and $\alpha=1.650$, $\beta=1.662$, and $\gamma=1.664$ for yellow light. The absorption axes coincide with the optic elasticity axes, with X=light brown, Y=yellowish brown with greenish tinge, Z=purple-reddish brown and Z>Y>X. This observation has been taken into consideration in Table 2.

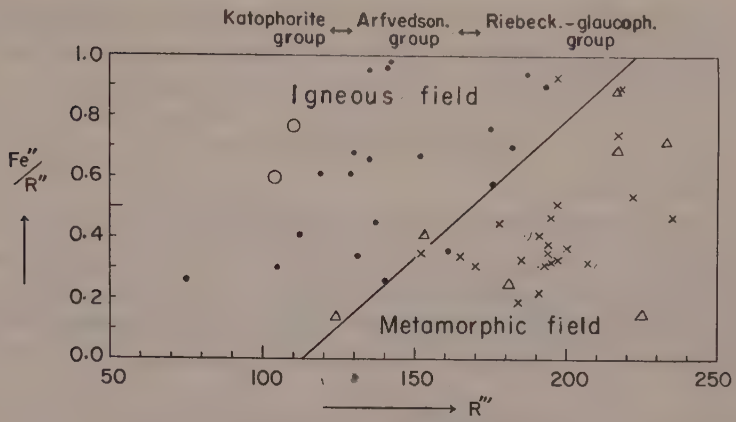

Fig. 7. The relation between the compositions and modes of occurrence of amphiboles of the riebeckite-arfvedsonite-katophorite series. Glaucophane is included. The open circles represent amphiboles of volcanic rocks, the points those of plutonic rocks and pegmatites, the crosses those of crystalline schists, and the triangles those of ironstones and others.

Certain writers claimed that riebeckite occurs in quartz-bearing alkalic rocks, while arfvedsonite occurs in nepheline-bearing ones, and that the degree of saturation with silica is the factor to determine which of the two is formed. However, this statement is not justified. Riebeckite can form in nepheline-bearing rocks as seen in Nos. 6 and 9 of Table 1, when the formation temperature is low.

In the arfvedsonite and katophorite groups the Fe'''/R''' ratio is high, whereas the riebeckite-glaucophane group includes not only members with high Fe'''/R''' values (riebeckite and magnesioriebeckite) but also those with low Fe'''/R''' values (glaucophane). Consequently, if we remove glaucophane from the riebeckite-arfvedsonite-katophorite series, the compositional variations of the remaining members will be expressed mainly in terms of the following two substitutions: R'''Si←→Ca R''Al and Mg←→Fe. Then the relation between their chemical compositions and optical properties can be represented in a rectangular diagram showing the two substitutions as coordinates. A tentative example of such diagrams is shown in Fig. 8. This diagram is very incomplete, because reliable optical data are too little.

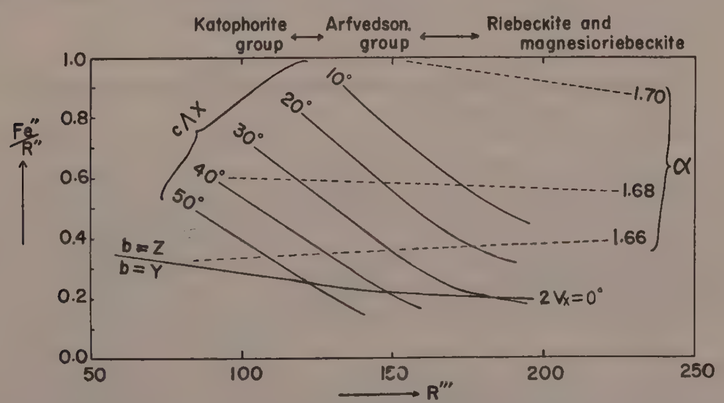

Fig. 8. The approximate relation between the compositions and optical properties of amphiboles of the riebeckite-arfvedsonite-katophorite series, excluding glaucophane.

Moreover, some members of this series may have suffered secondary change in optical properties owing to exsolution after formation of the crystals, as was discussed by Eskola and Sahlstein (1931b) and Sahama (1956).

IX. Soda-Tremolite Group

1. General statement

In some soda-tremolites, the R‴ content is too small to give a definite reliable value of Fe‴/R‴. As shown in Fig. 6C, the Fe‴/R‴ ratio is large, so far as determined, and the Fe″/R″ ratio is very small.

Probably there exist a continuous series of solid solution between soda-tremolite and tremolite (Sundius, 1946), and also between soda-tremolite and magnesioarfvedsonite.

Figs. 1 and 2 show that soda-tremolite is in serial relation with some of magnesioarfvedsonite and magnesioriebeckite. However, no further comment will be given of this series, because the series is of rather small petrological importance.

2. Optical properties

The optical properties of members of the soda-tremolite group are as follows: $b=Y$, $c \wedge Z=15°–45°$, $2V_x=66°–87°$, $\alpha=1.60–1.65$, $\gamma=1.62–1.66$, $\gamma-\alpha=0.009–0.022$. Some soda-tremolites are colorless and others show marked pleochroism from yellow to green, or from green to blue.

3. Modes of occurrence

Soda-tremolite occurs in metamorphosed limestone and jadeite-rock. It was found also in hydrothermally altered rocks associated with alkalic igneous rocks.

4. Names and Varieties

Imerinite (Lacroix, 1921) belongs to soda-tremolite.

Richterite is also a variety of soda-tremolite, usually rich in Mn. It occurs in metamorphosed limestone of Långban in Sweden and so on.

Szechenyiite (Krenner, 1900) is a soda-tremolite with a small R‴ value from a jadeite-rock of Burma.

Soda-tremolite was regarded erroneously as being closely related to glaucophane, and hence was called *tremolite-glaucophane* or so by certin writers. Such names should be rejected.

X. Colors and Formation Temperatures of the Amphiboles

In the whole family of amphibole, brown members are formed at higher temperatures than green and blue ones having resembling chemical compositions. Among the alkali-amphiboles, only katophorite is brown. It corresponds to the fact that katophorite is formed generally at higher temperatures than any other members of the alkali-amphiboles. Brown common hornblende occurs in gabbro, whereas green one occurs in diorite and granite. In metamorphic rocks, brownish common hornblende occurs at higher grades than blue-green one (Wiseman, 1934: Miyashiro, 1953). Barkevikite (brown) occurs in rocks which may be considered to have crystallized generally at higher temperatures than hastingsite (blue-green). Moreover, the marginal changes of katophorite to arfvedsonite (Broegger, 1894), of brown hornblende to greenish one, and of barkevikite to hastingsite in igneous rocks with falling temperature are known to take place.

The cause of this color variation is not clear. One might attribute it to some chemical differences. Indeed, some of the brown members are richer, for example, in Ti than the corresponding blue-green ones. However, there are many exceptions for such chemical differences. The color variation may be due to some slight structural difference in response to temperature difference.

XI. Aluminum in 4- and 6-Coordinations

WICKMAN (1943) and THOMPSON (1947) claimed that Al in 4-coordination tends to form at high temperatures, whereas Al in 6-coordination tends to form at high pressures. This rule holds splendidly in the alkali-amphiboles. Fig. 9 shows the amounts of Al in 4- and 6-coordiantions in the members of the alkali-amphiboles.

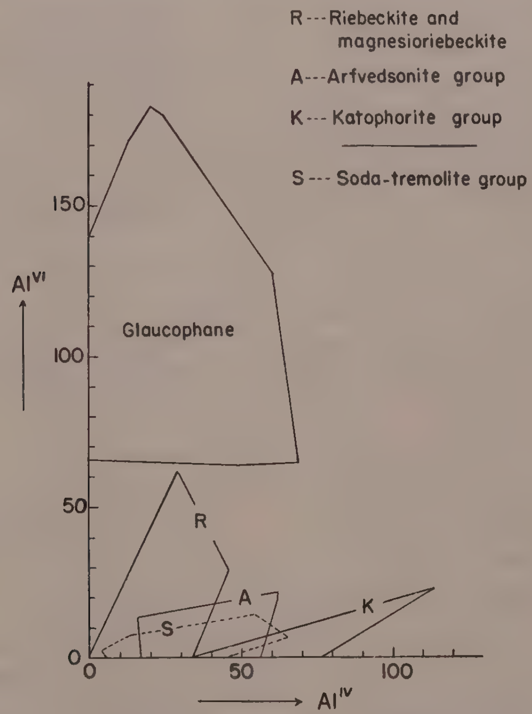

Fig. 9. The amounts of Al in 4- and 6-coordinations in the members of the alkali-amphiboles.

Glaucophane, being formed at high pressures, is very high in 6-coordinated Al. In the other members of the riebeckite-arfvedsonite-katophorite series, 6-coordinated Al decreases and 4-coordinated Al increases in the order from riebeckite and magnesioriebeckite through the arfvedsonite group to the katophorite group. This compositional variation corresponds to the order of decreaseing pressure and increasing temperature in their formation.

In albite and nepheline, Al is in 4-coordination, whereas in glaucophane and jadeite, Al is in 6-coordination. Then the formation of glaucophane and jadeite from albite, nepheline, and/or some mafic minerals is accompanied by an increase in the coordination number of Al. However, that glaucophane and jadeite are stable at higher pressures, is a result of the fact that their density is higher than the bulk

Table 1. Analyses of Alkali-Amphiboles Calculated

No.	Name and occurrence	Locality	Author
1	Riebeckite (crocid.) from ironstone	Hamersley Range, Australia	SIMPSON
2	Riebeckite from schist	Mill Creek, Calif.	SWITZER
3	Riebeckite from schist	Vallone delle Miniere, Piemont	GRILL
4	Riebeckite (crocid.) from ironstone	Kliphuis, S. Africa	PEACOCK
5	Riebeckite (crocid.) from ironstone	Hamersley Range, Australia	SIMPSON
6	Riebeckite (osannite) from metamor. neph. gneiss	Cevadaes, Portugal	HLAWATSCH
7	Riebeckite from quartz-syenite-pegmatite	Fukushin-zan, Korea	MIYASHIRO, 1956
8	Riebeckite from granite-pegmatite	Quincy, Mass.	PALACHE & WARREN
9	Riebeckite from neph.-syenite (?)	Mariupol, Ukraine	AINBERG
10	Riebeckite from quartz-syenite	Fukushin-zan, Korea	MIYASHIRO, 1956
11	Riebeckite from syenite-pegmatite	Alter Pedroso, Portugal	VENDL
12	Magnesioriebeckite (crocid.) from limestone	S. Australia	JACK
13	Magnesioriebeckite (ternovskite) from schist (?)	Krivoi Rog, Ukraine	POLOVINKINA
14	Magnesioriebeckite (crocid.) from metasediment	Cochabamba, Bolivia	AHLFELD
15	Magnesioriebeckite (fluotaram.) from syenite-pegmatite	Mariupol, Ukraine	MOROZEWICZ
16	Magnesioriebeckite (riebeck.-cross.) from metamor. rock	Glen Lui, Scotland	MCLACHLAN
17	Subglaucophane (glaucoph.) from gneiss	Alpe de Sevreu, Switz.	WOYNO
18	Subglaucophane (riebeck.) assoc. with schist	Saint-Véran, Hautes-Alpes	ROUTHIER
19	Subglaucophane (crossite) from schist	Vodno, Jugoslavia	NIKITIN & KLEMEN
20	Subglaucophane (crossite) from schist	Berkeley, Calif.	KUNITZ
21	Subglaucophane (crossite) from schist	Berkeley, Calif.	SWITZER
22	Subglaucophane (glaucoph.) from schist	Lavintzie, Switzerland	GRUBENMANN
23	Subglaucophane (crossite) from schist	Anglesey, Wales	HOLGATE
24	Ferroglaucophane (glaucoph.) from schist	Cykladen, Greece	KUNITZ
25	Glaucophane proper from prasinite	Rocca Bianca, Piemont	ZAMBONINI
26	Glaucophane proper from schist	Horokanai Pass, Hokkaido	SUZUKI
27	Glaucophane proper from schist	Syra, Greece	WASHINGTON
28	Glaucophane proper from schist	Champ de Praz, Piemont	KUNITZ
29	Glaucophane proper from schist	Smyrna, Turkey	KUNINZ
30	Glaucophane proper (gastaldite) assoc. with schist	St. Marcel, Piemont	ZAMBONINI
31	Glaucophane proper from schist	Zermatt, Switzerland	KUNITZ
32	Glaucophane proper from schist	San Pablo, Calif.	BLASDALE
33	Glaucophane proper from schist	San Pablo, Calif.	BLASDALE
34	Glaucophane proper from schist	Mt. Saleve, Switzerland	KUNITZ

to Atomic Ratios for O=2300 (Excluding H_2O)

No.	Si	Al^{IV}	Al^{VI}	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H_2O	F	R'''	Fe'''/R'''	F''/R''
1	792	1	0	0	233	189	0	74	8	181	6	+100	—	233	1.00	0.72
2	754	46	29	1	192	165	63	79	6	144	6	+44	0	222	0.87	0.54
3	783	17	32	0	186	218	3	23	13	230	22	+60	—	218	0.85	0.89
4	798	2	2	—	215	249	—	31	3	181	1	+132	—	217	0.99	0.89
5	789	4	0	0	217	194	0	89	6	177	5	+135	—	217	1.00	0.69
6	779	18	0	4	196	268	17	4	15	199	17	97	—	197	1.00	0.93
7	773	9	0	11	193	279	7	25	13	197	11	+105	22	193	1.00	0.90
8	793	7	5	15	167	274	15	2	21	181	22	+66	10	187	0.89	0.94
9	755	14	0	46	167	222	7	86	38	130	15	+173	—	182	0.92	0.70
10	796	4	7	5	164	188	19	115	22	145	41	+102	14	176	0.93	0.58
11	775	25	11	8	156	240	29	48	21	197	19	+105	22	175	0.89	0.76
12	771	29	61	—	164	41	0	234	7	176	13	+111	—	225	0.73	0.15
13	764	36	26	3	168	99	—	198	33	166	13	89	—	197	0.85	0.33
14	768	32	33	0	148	87	3	256	19	151	8	34	—	181	0.82	0.25
15	773	27	3	15	143	110	69	130	8	239	57	+67	116	161	0.89	0.36
16	757	34	0	16	146	136	2	191	77	142	14	+120	9	153	0.95	0.41
17	780	20	81	29	125	109	3	118	36	141	13	+78	—	235	0.53	0.47
18	802	0	66	1	150	208	2	70	12	150	8	+84	—	217	0.69	0.74
19	780	20	122	4	74	110	1	183	19	188	2	+57	—	200	0.37	0.37
20	781	19	120	—	75	141	4	154	24	175	7	+93	—	195	0.38	0.47
21	777	23	72	3	119	119	2	193	24	162	2	+96	1	194	0.61	0.38
22	750	50	64	10	111	100	—	199	34	198	20	+21	—	185	0.60	0.33
23	731	69	65	18	95	131	2	160	62	198	11	+57	—	178	0.53	0.45
24	776	24	180	—	17	160	—	153	6	182	15	94	—	197	0.09	0.51
25	780	20	182	—	25	93	0	195	31	157	6	+125	—	207	0.12	0.32
26	809	0	139	3	53	92	1	190	18	162	10	+65	—	195	0.27	0.32
27	784	16	161	—	33	110	1	199	14	179	7	+16	—	194	0.17	0.35
28	787	13	163	—	30	95	—	215	10	182	11	103	—	193	0.16	0.31
29	787	13	171	—	20	126	—	184	18	173	11	89	—	191	0.10	0.41
30	775	25	170	—	21	71	—	254	18	167	0	111	—	191	0.11	0.22
31	780	20	172	—	12	61	—	262	15	183	12	102	—	184	0.07	0.19
32	740	60	128	2	40	108	0	239	46	168	0	+121	—	170	0.24	0.31
33	762	38	114	4	47	115	5	215	30	205	3	+83	—	165	0.28	0.34
34	781	19	127	—	25	123	—	231	49	149	10	85	—	152	0.16	0.35

Table 1 (Continued)

No.	Name and occurrence	Locality	Author
35	Arfvedsonite	Hackmannschlucht	KUNITZ
36	Arfvedsonite (heikolite) from granite pegmatite	Fukushin-zan, Korea	MIYASHIRO, 1956
37	Arfvedsonite from neph.-syenite	Kangerdluarsuk, Greenland	SAHAMA
38	Arfvedsonite from neph.-syenite	Kangerdluarsuk, Greenland	KUNITZ
39	Arfvedsonite from pegmatite	Urma-varaka, Kola Penin.	KUPLETSKIJ
40	Arfvedsonite from pegmatite	Kakasnjujakok, Kola Penin.	KUNITZ
41	Arfvedsonite from neph.-syenite	Loparsky Pass, Kola Penin.	KUNITZ
42	Arfvedsonite (riebeck.-arfved.) from neph.-syenite	Kiihtelysvaara, Finland	ESKOLA & SAHLSTEIN
43	Arfvedsonite from neph.-syenite	Los-Archipel, W. Africa	KUNITZ
44	Magnesioarfvedsonite (torendrikite) from syenite	Ambatofinandrahana, Madagascar	LACROIX, 1920
45	Magnesioarfvedsonite (fluotaramite) from syenite pegm.	Mariupol, Ukraine	MOROZEWICZ
46	Magnesioarfvedsonite (fluotaramite) from syenite pegm.	Mariupol, Ukraine	AINBERG
47	Magnesioarfvedsonite from hydrothermal rock	Iron Hill, Colorado	LARSEN
48	Magnesioarfvedsonite (fluotaramite) from syenite pegm.	Mariupol, Ukraine	MOROZEWICZ
49	Katophorite from sanidinite inclusion in trachyte	Sao Miguel, Azores	OSANN, 1888
50	Katophorite from trachyte	Fuente Vaca	KUNITZ
51	Magnesiokatophorite (anophorite) from shonkinite	Katzenbuckel, Odenwald	FREUDENBERG
52	Magnesiokatophorite (Katophorite)	Chibinpachk, Kola Penin.	KUNITZ
53	Magnesiokatophorite from theralite	Crazy Mts., Montana	WOLFF
54	Soda-tremolite from metamorphic rock (?)	Krivoi Rog, Ukraine	POLOVINKINA
55	Soda-tremolite (asbestos) from lead deposit	Camp Albion, Colorado	WAHLSTROM
56	Soda-tremolite from hydrothermal rock	Iron Hill, Colorado	LARSEN
57	Soda-tremolite from hydrothermal rock	Iron Hill, Colorado	LARSEN
58	Soda-tremolite from hydrothermal rock	Iron Hill, Colorado	LARSEN
59	Soda-tremolite (imerinite) from limestone	Ambatoharina, Madagascar	LACROIX, 1921
60	Soda-tremolite from hydrothermal rock	Iron Hill, Colorado	LARSEN
61	Soda-tremolite from hydrothermal rock	Iron Hill, Colorado	LARSEN
62	Soda-tremolite (richterite) from limestone	Långban, Sweden	SUNDIUS, 1945
63	Soda-tremolite (richterite) from limestone	Långban, Sweden	SUNDIUS, 1945

Note. In the original descriptions, amphibole No. 53 was erroneously called "hastingsite", and amphiboles Nos. 47 and 54 were unfortunately called "soda-tremolite-glaucophane" and "tremolite-glaucophane" respectively. The optical properties of amphibole No. 44 were re-examined by WINCHELL (1925).

Table 1 (Continued)

No.	Si	Al^{IV}	Al^{VI}	Ti	Fe'''	Fe''	Mn	Mg	Ca	Na	K	H_2O	F	R'''	Fe'''/R'''	Fe''/R''
35	737	52	0	25	141	212	16	110	37	207	17	100	—	155	0.91	0.63
36	745	55	9	13	130	246	13	106	43	143	28	+148	—	152	0.86	0.67
37	742	58	17	6	119	343	0	6	35	203	59	+66	—	142	0.84	0.98
38	775	25	1	12	128	339	6	7	17	219	31	110	—	141	0.91	0.96
39	738	62	21	10	104	353	10	10	53	163	34	60	—	135	0.77	0.95
40	734	56	0	26	119	234	18	100	58	191	24	86	—	135	0.88	0.66
41	741	50	0	24	115	241	10	103	52	211	21	98	—	130	0.89	0.68
42	738	62	19	23	87	210	6	126	46	240	35	55	—	129	0.67	0.61
43	751	49	1	24	94	232	11	134	30	232	17	104	—	119	0.79	0.61
44	773	17	0	5	140	97	—	273	58	145	17	6	5	140	1.00	0.26
45	752	48	13	7	117	157	5	185	57	179	41	+82	83	137	0.85	0.45
46	765	25	0	10	131	131	7	242	41	156	35	+104	80	131	1.00	0.34
47	750	50	5	14	105	50	2	317	60	192	9	+59	35	124	0.85	0.14
48	784	16	13	13	86	147	8	207	54	196	39	+72	97	112	0.77	0.41
49	715	76	0	—	110	311	39	57	82	185	18	—	—	110	1.00	0.76
50	724	67	0	19	94	233	19	135	80	187	19	79	—	104	0.90	0.60
51	729	34	0	59	83	112	4	253	50	225	34	74	—	105	0.79	0.30
52	686	114	23	11	61	105	15	288	121	126	33	91	—	95	0.64	0.26
53	703	97	16	14	45	115	2	319	87	169	41	+71	—	75	0.60	0.26
54	748	52	11	12	87	0	—	366	115	144	5	69	—	110	0.79	0.00
55	787	13	7	3	88	31	—	361	40	218	32	40	—	98	0.90	0.08
56	746	54	14	5	72	77	4	331	69	203	14	+76	19	91	0.79	0.19
57	769	31	3	0	79	35	6	374	50	214	38	+29	96	82	0.96	0.08
58	735	65	7	6	46	62	3	380	101	151	39	+7	—	59	0.78	0.14
59	753	45	0	4	50	55	—	430	41	202	32	40	41	52	0.96	0.11
60	783	12	0	3	49	10	1	451	91	138	32	+40	57	49	1.00	0.02
61	791	5	0	3	42	29	7	429	77	148	54	+113	0	42	1.00	0.06
62	775	23	0	1	20	0	106	396	84	157	32	92	16	20	indef.	0.00
63	796	4	2	0	3	0	28	486	133	84	11	110	16	5	indef.	0.00

Table 2. Optical Properties of Analyzed Alkali-Amphiboles

No.	α	β	γ	$\gamma-\alpha$	2V over X	Disp.	Optic	Orient.
2	1.680	1.683	1.685	0.005	50°		b=Z,	c∧Y=5°
3		1.692						c∧X=4°
4	1.698	1.699	1.706	0.008			b=Z,	c∧X=0°
6		1.693						
7	1.701	1.711						
8		1.695					b=Z,	c∧X=4-5°
9	1.688		1.691	0.003	112°	$\rho<v$	b=Z,	c∧Y=1°
10		1.686						
11		1.6934					b=Z,	c∧X=2°
13	1.655	1.664	1.668	0.013	42°		b=Y,	c∧Z=27-35°
16	1.668		1.680	0.012	50°		b=Z,	c∧X=14°
19		1.645		0.011	12-65°		b=Z,	c∧Y=8°
20	1.640		1.652	0.012			b=Y,	c∧Z=3°
21	1.659	1.663	1.666	0.007	50°	$\rho>v$	b=Z,	c∧Y=2°
23	1.649	1.656	1.657	0.008	17°		b=Y,	c∧Z=11°
24	1.622		1.640	0.018			b=Y,	c∧Z=5-6°
26		1.660			10-15°	$\rho>v$	b=Y,	c∧Z=8-14°
28	1.615		1.634	0.019	41°		b=Y,	c∧Z=6-8°
29	1.618		1.637	0.019			b=Y,	c∧Z=4°
31	1.606		1.627	0.021			b=Y,	c∧Z=8°
34	1.619		1.640	0.021				c∧Z=6°
35	1.690	1.695					b=Z,	c∧X=27°
36	1.680	1.687	1.691	0.011			b=Z	
37	1.696	1.700	1.705	0.009			b=Z,	c∧X=0°
38	1.695	1.698			large		b=Z,	c∧X=8°
39	1.695		1.700	0.005			b=Z,	c∧X=7°
40	1.688	1.693					b=Z,	c∧X=30°
41	1.687	1.693					b=Z,	c∧X=28°
42	1.670	1.680	1.682	0.012	small		b=Z,	c∧X=20-25°
43	1.683	1.687					b=Z,	c∧X=15°
44		1.665					b=Z,	c∧Y=ca. 40°
46	1.655		1.664	0.009	41°	$\rho>v$	b=Z,	c∧X=18-30°
47	1.651	1.661	1.670	0.019	(72°)	($\rho>v$)		c∧Z=57°
50	1.681	1.688					b=Z,	c∧X=36°
51					ca. 25°	$\rho>v$	b=Z,	c∧X=63-70°
52	1.655		1.662	0.007	(small)		b=Y,	c∧X=56°
53	1.639	1.658	1.660	0.021	38°	$\rho<v$	b=Y,	c∧X=52°

Table 2 (Continued)

No.	α	β	γ	$\gamma-\alpha$	2V over X	Disp.	Optic	Orient.
54	1.621		1.640	0.019	76–80°			c∧Z=15°
55	1.633	1.639	1.642	0.009				c∧Z=44°
56	1.650	1.657	1.659	0.009	(64°)			c∧Z=35°
57	1.623	1.633	1.641	0.018	(87°)	($\rho>v$)		c∧Z=40°
58	1.628	1.638	1.644	0.016	(82°)	($\rho>v$)		c∧Z=24°
59							b=Y,	c∧Z=45°
60	1.612	1.623	1.627	0.015				c∧Z=20°
61	1.606	1.616	1.623	0.017				c∧Z=24°
62	1.622	1.635	1.641	0.019	66°		b=Y,	c∧Z=19°
63	1.605		1.627	0.022			b=Y,	c∧Z=17°

Note. The analysis numbers are common to Tables 1 and 2. In amphiboles Nos. 47, 52, 56, 57 and 58, it is not clear whether the value of their optical angle was measured over X or over Z. The accompanying axial dispersion was observed probably over the acute bisectrix, which is either X or Z. These values of optical angle and accompanying axial dispersion are shown in brackets. In the remaining amphiboles, the optical angle and axial dispersion are shown in regard to X.

Table 3. Representative Examples of Chemical Analyses of Alkali-Amphiboles

No.	8	37	49	27	60
SiO_2	51.79	44.61	45.53	57.67	56.74
Al_2O_3	0.68	4.02	4.10	11.07	0.71
TiO_2	1.28	0.48	—	—	0.28
Fe_2O_3	14.51	9.92	9.35	3.20	4.71
FeO	21.43	25.79	23.72	9.68	0.87
MnO	1.15	0.00	2.96	0.06	0.07
MgO	0.10	0.25	2.46	9.85	21.95
CaO	1.28	2.06	4.89	0.95	6.15
Na_2O	6.16	6.58	6.07	6.80	5.15
K_2O	1.10	2.89	0.88	0.42	1.80
H_2O+	1.30	1.24	—	0.36	0.87
H_2O-	0.10	0.00	—	0.12	0.00
F	0.20	—	—	—	1.30
	101.08	99.84	99.96	100.18	100.91
O=F	0.09				0.54
	100.99				100.37

No. 8: Riebeckite from Quincy, Mass. By PALACHE and WARREN (1911).
No. 37: Arfvedsonite from Kangerdluarsuk, Greenland. By SAHAMA (1956).
No. 49: Katophorite from Sao Miguel, Azores. By OSANN (1888).
No. 27: Glaucophane proper from Syra, Greece. By WASHINGTON (1901).
No. 60: Soda-tremolite from Iron Hill, Colorado. Contains also SrO 0.02, NiO 0.23, Cr_2O_3 0.06. By LARSEN (1942).

density of the isochemical assemblages containing albite and/or nepheline. It follows that the stability of 6-coordinated Al at higher pressures is based on that 6-coordinated Al makes more closely packed structures possible in silicates than 4-coordinated one in most cases at least.

Therefore, if the increase of the coordination number is accompanied by decrease in density, the crystals with a higher coordination become stable at lower pressures. A good example for this relation is found in andalusite, having 5-coordinated Al, and sillimanite, having 4-coordinated Al, both together with 6-coordinated Al. Andalusite is stable on the lower-pressure side of the andalusite-sillimanite stability boundary as pointed out by MIYASHIRO (1949) and THOMPSON (1955). (Kyanite, stable at higher pressures than the two, has 6-coordinated Al only.)

Crystals stable at higher pressures have generally a smaller entropy, and hence are stable at lower temperatures (THOMPSON, 1955, p. 70).

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XIII. Alphabetical List of the Names of the Subdivisions in the Alkali-Amphiboles

V ....Riebeckite-glaucophane group.
VI ....Arfvedsonite group.
VII ....Katophorite group.
IX ....Soda-tremolite group.

Anophorite (VII)
Arfvedsonite (VI)
Cataphorite (VII)
Crocidolite (V)
Crossite (V)
Ferroglaucophane (V)
Fluotaramite (VI and V)
Gastaldite (V)
Glaucophane (V)
Glaucophane proper (V)
Heikolite (VI)
Imerinite (IX)
Kataphorite (VII)
Katoforite (VII)
Katophorite (VII)
Magnesioarfvedsonite (VI)
Magnesiokatophorite (VII)
Magnesioriebeckite (V)
Osannite (V)
Richterite (IX)
Riebeckite (V)
Soda-tremolite (IX)
Subglaucophane (V)
Szechenyiite (IX)
Ternovskite (V)
Torendrikite (VI and V)

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